The Welding Journal

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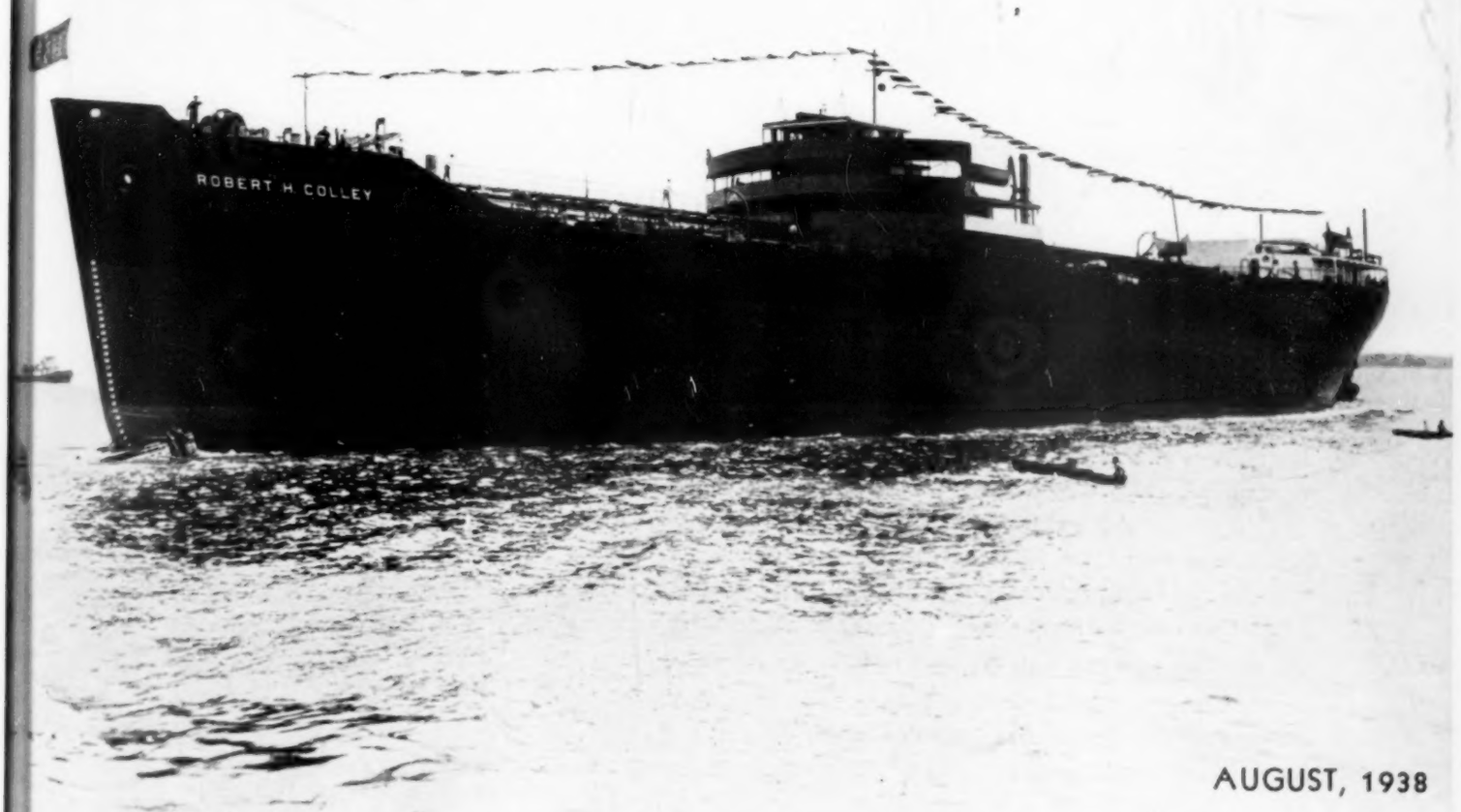

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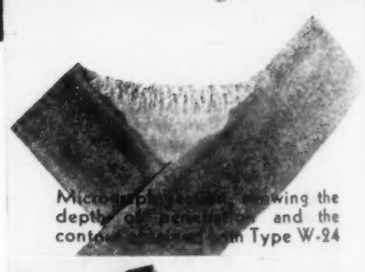

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Welding Journal

VOLUME 17, No. 8 AUGUST 1938

Welding in Modern Building Construction*

By HEATH LAWSON†

THE most ardent welding enthusiasts in the structural field have advocated the adoption of all-welded structures for many years and have at times felt rather disheartened at the apparent reluctance of engineers and fabricators to go "all the way" in welded designs.

The present outlook for welded fabrication of structural steel should discourage no one; economic laws still operate and the point has been about reached where combinations of welding, bolting and riveting are employed to produce the cheapest structure. It must not be lost sight of that riveting is a well established practice and a highly developed art. That with present welding costs some economy of design or detail is necessary if welding is to be substituted for riveting. In fact, a new welding process or a vast improvement in present processes is necessary before riveting can be entirely supplanted.

There are many material advantages peculiar to welding, such as simpler, neater looking details, the elimination of fills, the advantage of retention of full section and others. Welding is, therefore, being adopted for the fabrication of elements of what may be termed riveted structures. Introduction of the cutting torch and welding equipment has resulted in many minor changes in shop methods. In a riveted building, for example, where cover plates are to be added to column sections of a thickness requiring drilled holes, it is common practice to tack weld the plates to the column shaft and drill in one operation. A similar use of tack welding was made in the fabrication of the towers for the Golden Gate Bridge.

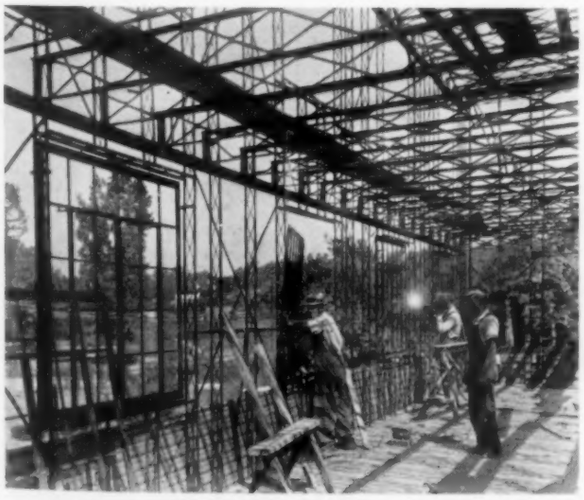


Fig. 1—Setting Steel Sash and Welding in Steel Frame House

Fig. 2—Steel Frame House—Welding Rafters to Ridge

It has become common practice in riveted structures to fabricate by welding the connections of base angles to column slabs, the attachment of masonry plates to spandrel sections and lintels and similar details where lower costs are attained by doing away with countersunk holes or by eliminating drilled holes in thick materials. Another common detail is the welding of plate stiffeners under concentrated loads on rolled sections, replacing the usual riveted stiffener angles.

Many structures are designed for combinations of welding, riveting and bolting. For example, greater economy is made possible in a welded structure by bolting connections of secondary members. In a field riveted structure, shop welding is used on such items as trussed purlins, trusses, rigid frames, shaped beams and similar details. Such combinations skillfully used result in lower costs.

Some combinations, however, are definitely uneconomical. A shop-riveted, field-welded structure is generally uneconomical because the economy of welded details is lost. Field riveting in combination with field welding is also usually uneconomical, unless the extra cost of transportation and the increased rental charges on the erection equipment can be absorbed in a large operation, or some unusual advantage may be obtained to offset these charges.

Use of steel in single residences offers great opportunities for welding, both in shop and field. The division of welding between the shop and the field varies widely. Consideration has been given to complete shop fabrication and towing the completed house to the site. However, the most common practice is shop fabrication of standard panels, which are assembled in the field by bolting or welding.

* Presented at Annual Meeting of Philadelphia Section, A. W. S., held April 18th.

† Engineer, Fabricated Steel Construction Division, Bethlehem Steel Company, Bethlehem, Pa.

Fig. 3—Completed Steel Frame House

A third approach has been to ship steel studs and joists to the site with little shop fabrication, assembling the frame in a manner almost identical with that used in the erection of wooden framing. Thus, the cutting torch replaces the carpenter's saw and electric welding, his hammer and nails. Cutting and arc welding give to steel the same flexibility in design and arrangement as obtained in wooden framing, no extra material is needed for connections and the need of expensive detailed fabricating drawings is eliminated. The development of light, inexpensive welding equipment is adding impetus to this third method. Construction details and a finished steel frame house are shown in Figs. 1-3.

In a report of a meeting of the American Institute of Steel Construction (THE WELDING JOURNAL, Nov. 1937) F. T. Llewellyn is quoted as stating that over 1400 houses have been built in which steel is the major material of construction, while over 3000 use steel in a lesser degree.

The standard open web steel joists are well known and widely used. Completely shop fabricated, to be supported on masonry walls or structural steel beams, the welded type of open web joists are fabricated by electric or pressure welding, of standard Tee's, angles and bars. The standard joists will accommodate spans up to 32 feet while long-span, shop-fabricated, arc-welded trusses are available for spans to 64 feet.

In the design of mill buildings covering large areas, such as those used in the automobile and aviation industries several new developments have taken place, influenced in some respects by arc welding. One is the greater use of cantilever or continuous action in trusses or bent beams to obtain greater spans, and wider working-aisles. Another is the use of a bent or shaped beam. When column and beam are welded into one unit this form has been referred to as tree-form construction. It is used to reduce shadows in the working area and it is thought to produce a more pleasing interior (Fig. 4).

Arches and some forms of rigid frames lend themselves particularly well to welding. These are usually formed of rolled sections, split with the cutting torch and gussets welded in, to form a smooth surface. This construction is particularly pleasing to the eye when well proportioned and carefully fabricated. Some typical examples are given in Figs. 5 and 6.

A group of welded arch ribs for a large structure is shown in Fig. 7. The span of arch is 76 feet 6 inches, the height 36 feet 6 inches, the weight of each rib 9.6 tons. Cover plates were welded along edges and plug-welded at center. Field splices are used above each haunch, and at center of arch.

While welding has not been used in very tall buildings except for minor alterations, its use in modern tier buildings is increasing. Many such structures under ten stories have been built of welded construction. Most of them are hospitals, where elimination of noise is the main consideration, but there are also many schools, light manufacturing buildings and plant office buildings.

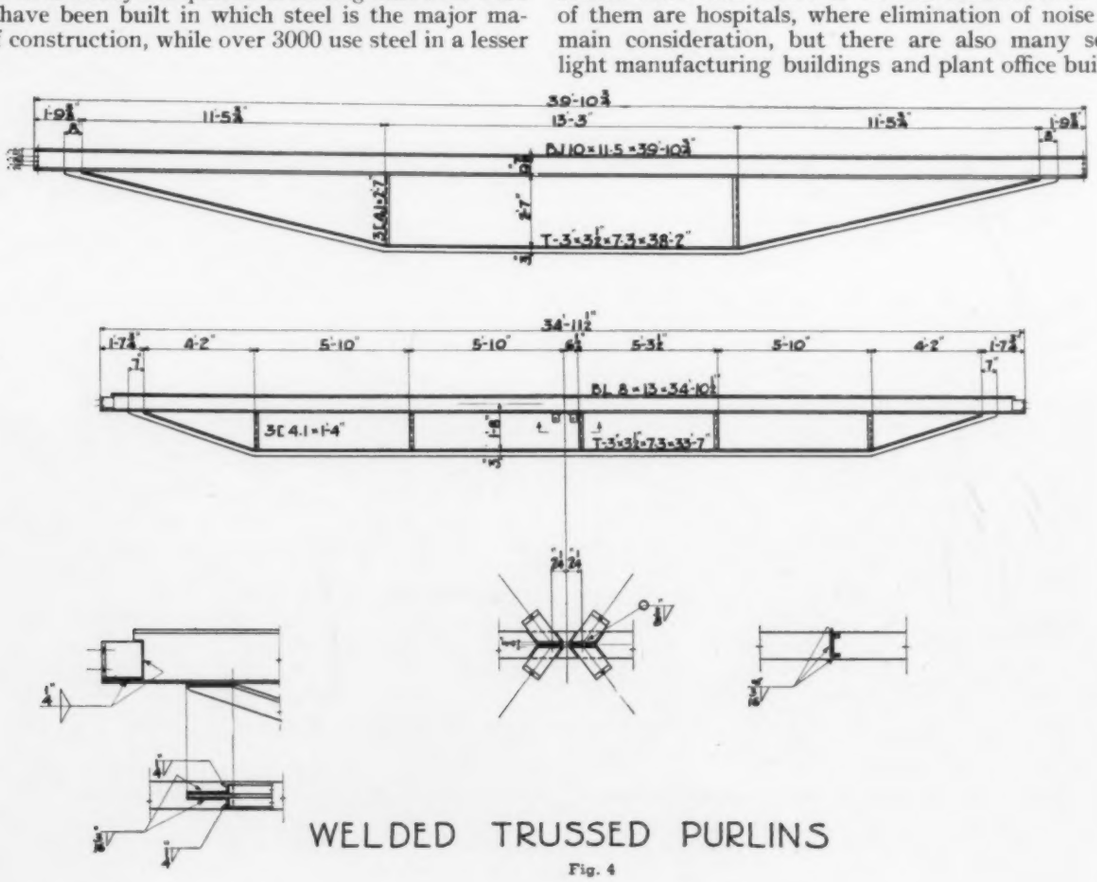


Fig. 4

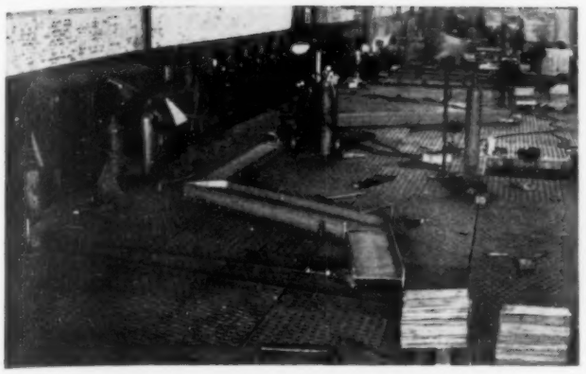


Fig. 5—Bending and Fitting Operation on Shaped Beams

Adoption of new building code provisions permitting welded construction by such cities as New York and Chicago, together with the demand for noise abatement, should stimulate welded construction in this class of structure. Incidentally there are 67 cities over 25,000 population, 26 of which are over 100,000, having welding provisions in the building code in general conformity with the A. W. S. Code; in 29 more cities welding may be used by special permit. Indications of the present trend are a fourteen-story apartment house now under construction in New York, and a fifteen-story hospital in Pittsburgh. In the latter field bolting is used for secondary members; all other connections are shop and field welded. Incidentally, this is probably the largest building in which A.C. welding equipment is used for field welding. Three welders are keeping so close behind the raising gang on this job that plumbing-up guys are never more than one tier behind the derrick. Typical details of this building are shown in Fig. 8.

In order to reduce shop costs holes were punched only in the filling-in beams which required holes for tie-rods, due to the type of floor used. As far as possible no holes were used in the main material of girders and columns.

Reduction in costs through elimination of shop operations can only be attained when the fabricator has control of the design of the details; and if the customer is to obtain any advantage from such economies the fabricator must know when preparing his estimate, that he will be in a position to effect such economies.

The preparation of details for a building of this size, without "standard details," such as we have for riveted construction, is a rather tedious procedure, since welded details require much more careful design. Many of the practices and assumptions common to riveted construction would be extremely bad practice for welded connections. For example, it is common practice in riveted designs to assume a free-end condition in a member, and to take no special precautions to produce a connection which approximates that condition. For riveted connections this is not serious, since these connections employ relatively thin angles, connected at relatively large distances from the back of the angle, producing a connection which is inherently flexible.

In welded construction, on the other hand, angles are not required for connections. Direct welding of the component parts or connections employing small bars and plates are sometimes used. Such details are inherently rigid; to attach such a detail with welding which is insufficient to resist the degree of restraint produced by the form of connection would likely result in weld failure.

Some examples of rigid and non-rigid welded connections are shown in Fig. 9. The diagram in the upper right-hand corner of this illustration is based on one shown in an article by H. M. Priest (AMERICAN WELDING SOCIETY JOURNAL, August 1933); it indicates the amount of movement or displacement at the top flange of a simple beam. As this movement of 0.1 inch must be absorbed or resisted by the top connection, it is evident from the sketches at upper left and center that details of this character could not permit so great a movement, nor are the welds sufficiently strong to restrain the beam to prevent such movement. This may result in tearing off the connection before the design load is attained. The flexible connections shown below these sketches would permit such movement, without damage to the connection, even though the yield point of the connection material be exceeded.

The lower right-hand sketch indicates how welds

Fig. 7—Shop Assembly of Arch Ribs

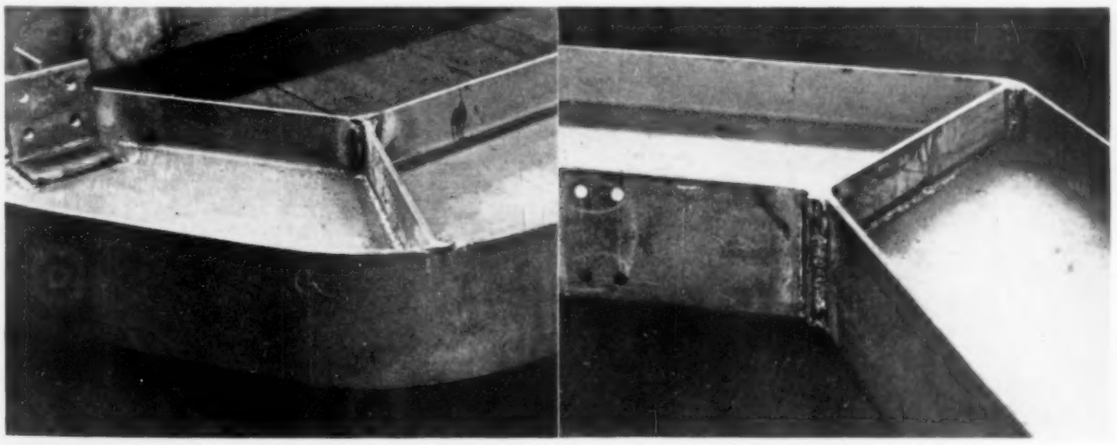


Fig. 6—Close-Up of Welded Joints

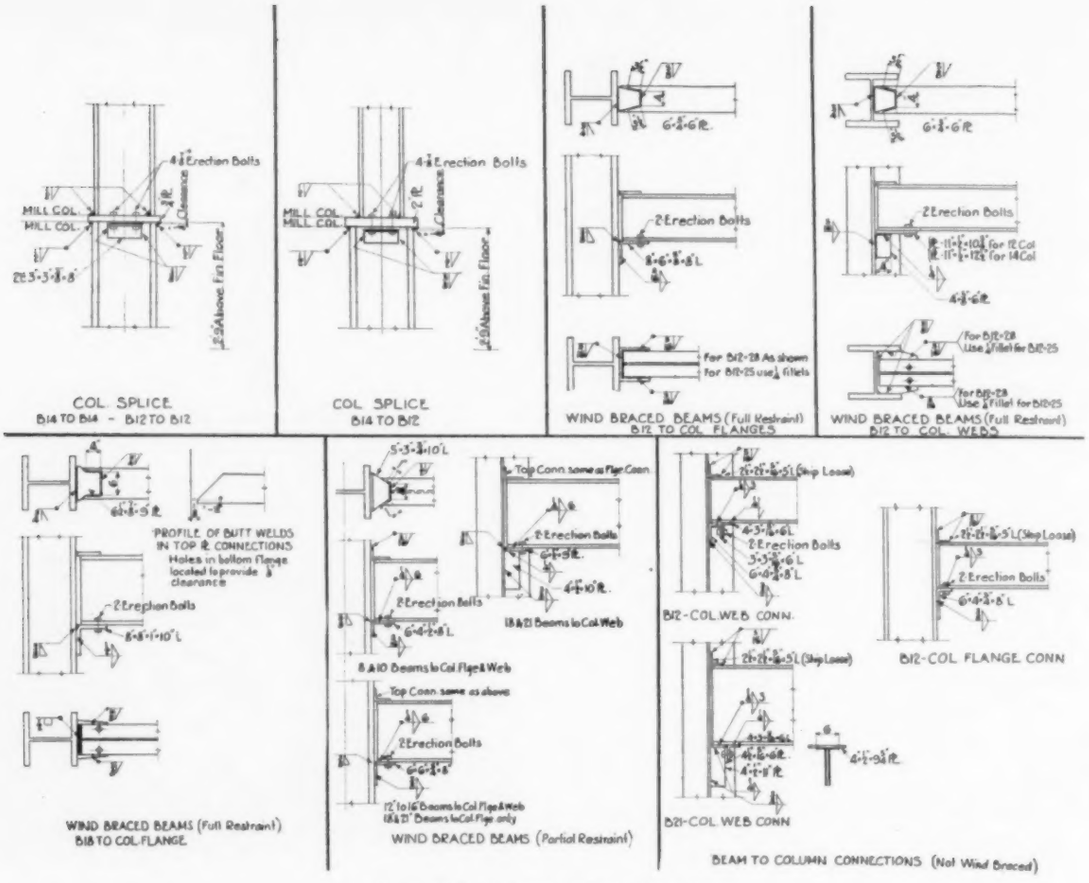

COL. SPLICE
B14 TO B14 - B12 TO B12
COL. SPLICE
B14 TO B12
WIND BRACED BEAMS (Full Restraint)
B12 TO COL. FLANGES
WIND BRACED BEAMS (Full Restraint)
B12 TO COL. WEBS
WIND BRACED BEAMS (Full Restraint)
B18 TO COL. FLANGE
WIND BRACED BEAMS (Partial Restraint)
B12-COL. WEB CONN.
B12-COL. FLANGE CONN.
B21-COL. WEB CONN.
BEAM TO COLUMN CONNECTIONS (Not Wind Braced)

Fig. 8—Typical Details, Hospital Building

should be placed on flexible connections, in order that the connection may flex without damage to the welds. The lower sketch indicates the preferred method.

If welded details could be standardized and published in the Steel Manufacturers Manuals, designers, detailers and the shop would benefit. However, this is not possible with present welding costs, as the cost of excess welding would put welding completely out of the picture.

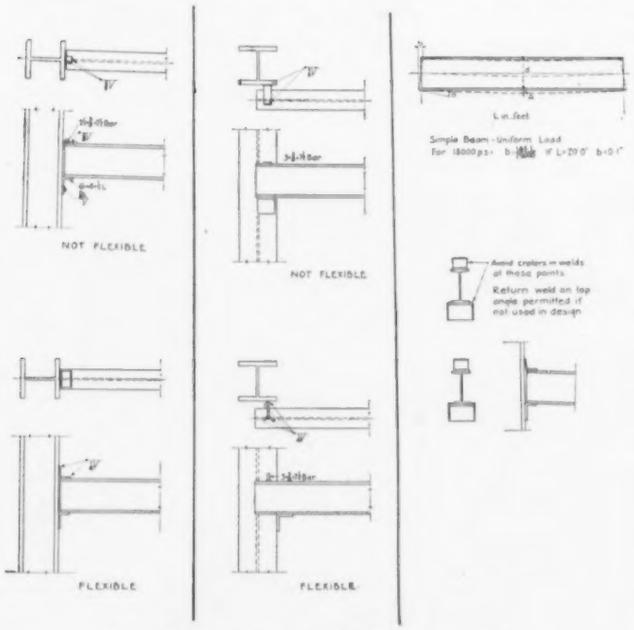


Fig. 9—Rigid and Non-Rigid Welded Connections

The standard riveted connection for a 15-inch standard 42.9-lb. beam, for example, contains 4 shop and 8 field rivets, all of which are required on a span of 7 feet. On a span of 14 feet or over, half as many rivets would develop the full strength of the beam; but it has been the custom to retain the standard connection regardless of span and to assume that drafting, punching and other standardized procedures are sufficiently cheapened thereby to pay for the excess riveting. With welded connections this attitude is impracticable. The cost is not in punch set-ups and the like—it is in the welder's time. Therefore, weld lengths must be figured down to some more reasonable relationship to the actual loads. There is no such thing as a standard welded connection for 15-inch beams which can be applied regardless of the length and loading, for the resultant cost of wasted welding could not be borne.

It is possible, however, to standardize on types of connections, and prepare charts and tables to facilitate the selection of details. By a judicious grouping of connections for a particular structure, job standards may then be set up.

Design Table and Charts, Fig. 10 and Figs. 11 to 22 are used for designing welded details. These are all based on A. I. S. C. 1936 Specifications and A. W. S. 1937 Specifications. Figures 10 and 11 need no explanation; Figs. 12 to 15 are also self-explanatory as all formulas are given. They are merely single and double welds under various combined shear and moment conditions; Fig. 16 is a standard connection angle detail.

Figures 17 and 21 are used in conjunction, as the ec-

Fig. 10

Allowable Loads on Fillet Welds

$P = 9.6DL$

(Based on 13,600 p.s.i. shear on throat = 9.6 K/a" on leg)

D = Weld Size in inches
L = Weld Length in inches
P = Allowable load in Kips

L \ D	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
.5	.6	.9	1.2	1.5	1.8	2.1	2.4	3.	3.6	4.2	4.8
1.0	1.2	1.8	2.4	3.0	3.6	4.2	4.8	6.	7.2	8.4	9.6
1.5	1.8	2.7	3.6	4.5	5.4	6.3	7.2	9.	10.8	12.6	14.4
2.0	2.4	3.6	4.8	6.0	7.2	8.4	9.6	12.	14.4	16.8	19.2
2.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	15.	18.0	21.0	24.0
3.0	3.6	5.4	7.2	9.0	10.8	12.6	14.4	18.	21.6	25.2	28.8
3.5	4.2	6.3	8.4	10.5	12.6	14.7	16.8	21.	25.2	29.4	33.6
4.0	4.8	7.2	9.6	12.0	14.4	16.8	19.2	24.	28.8	33.6	38.4
4.5	5.4	8.1	10.8	13.5	16.2	18.9	21.6	27.	32.4	37.8	43.2
5.0	6.0	9.0	12.0	15.0	18.0	21.0	24.0	30.	36.0	42.0	48.0
5.5	6.6	9.9	13.2	16.5	19.8	23.1	26.4	33.	39.6	46.2	52.8
6.0	7.2	10.8	14.4	18.0	21.6	25.2	28.8	36.	43.2	50.4	57.6
6.5	7.8	11.7	15.6	19.5	23.4	27.3	31.2	39.	46.8	54.6	62.4
7.0	8.4	12.6	16.8	21.0	25.2	29.4	33.6	42.	50.4	58.8	67.2
7.5	9.0	13.5	18.0	22.5	27.0	31.5	36.0	45.	54.0	63.0	72.0
8.0	9.6	14.4	19.2	24.0	28.8	33.6	38.4	48.	57.6	67.2	76.8
8.5	10.2	15.3	20.4	25.5	30.6	35.7	40.8	51.	61.2	71.4	81.6
9.0	10.8	16.2	21.6	27.0	32.4	37.8	43.2	54.	64.8	75.6	86.4
9.5	11.4	17.1	22.8	28.5	34.2	39.9	45.6	57.	68.4	79.8	91.2
10.0	12.0	18.0	24.0	30.0	36.0	42.0	48.0	60.	72.0	84.0	96.0
10.5	12.6	18.9	25.2	31.5	37.8	44.1	50.4	63.	75.6	88.2	100.8
11.0	13.2	19.8	26.4	33.0	39.6	46.2	52.8	66.	79.2	92.4	105.6
11.5	13.8	20.7	27.6	34.5	41.4	48.3	55.2	69.	82.8	96.6	110.4
12.	14.4	21.6	28.8	36.	43.2	50.4	57.6	72.	86.4	100.8	115.2
13.	15.6	23.4	31.2	39.	46.8	54.6	62.4	78.	93.6	109.2	124.8
14.	16.8	25.2	33.6	42.	50.4	58.8	67.2	84.	100.8	117.6	134.4
15.	18.0	27.0	36.0	45.	54.0	63.0	72.0	90.	108.0	126.0	144.0
16.	19.2	28.8	38.4	48.	57.6	67.2	76.8	96.	115.2	134.4	153.6
17.	20.4	30.6	40.8	51.	61.2	71.4	81.6	102.	122.4	142.8	163.2
18.	21.6	32.4	43.2	54.	64.8	75.6	86.4	108.	129.6	151.2	172.8
19.	22.8	34.2	45.6	57.	68.4	79.8	91.2	114.	136.8	159.6	182.4
20.	24.0	36.0	48.0	60.	72.0	84.0	96.	120.	144.0	168.0	192.0
21.	25.2	37.8	50.4	63.	75.6	88.2	100.8	126.	151.2	176.4	201.6
22.	26.4	39.6	52.8	66.	79.2	92.4	105.6	132.	158.4	184.8	211.2
23.	27.6	41.4	55.2	69.	82.8	96.6	110.4	138.	165.6	193.2	220.8
24.	28.8	43.2	57.6	72.	86.4	100.8	115.2	144.	172.8	201.6	230.4
25.	30.0	45.0	60.0	75.	90.0	105.0	120.0	150.	180.0	210.0	240.0
26.	31.2	46.8	62.4	78.	93.6	109.2	124.8	156.	187.2	218.4	249.6
27.	32.4	48.6	64.8	81.	97.2	113.4	129.6	162.	194.4	226.8	259.2
28.	33.6	50.4	67.2	84.	100.8	117.6	134.4	168.	201.6	235.2	268.8
29.	34.8	52.2	69.6	87.	104.4	121.8	139.2	174.	208.8	243.6	278.4
30.	36.0	54.0	72.0	90.	108.0	126.0	144.0	180.	216.0	252.0	288.0

Fig. 11

Allowable Total Tension on Butt Welds

$P = 15.6TL$

Note! Form of V varies for different Plate thicknesses as a matter of welding technique. Strength is not affected.

P = Allowable Load in Kips
T = Weld throat in inches
L = Weld length in inches
T and L are interchangeable in this table.

L \ T	3/16"	1/4"	5/16"	3/8"	7/16"	1/2"	9/16"	5/8"	11/16"	3/4"	13/16"	7/8"	15/16"	1"
1"	2.9	3.9	4.9	5.9	6.8	7.8	8.8	9.7	10.7	11.7	12.7	13.7	14.6	15.6
1¼"	3.7	4.9	6.1	7.3	8.5	9.8	11.0	12.2	13.4	14.6	15.8	17.1	18.3	19.5
1½"	4.4	5.9	7.3	8.8	10.2	11.7	13.2	14.6	16.1	17.6	19.0	20.5	21.9	23.4
1¾"	5.1	6.8	8.5	10.2	11.9	13.7	15.4	17.1	18.8	20.5	22.2	23.9	25.6	27.3
2"	5.8	7.8	9.7	11.7	13.7	15.6	17.5	19.5	21.4	23.4	25.4	27.3	29.2	31.2
2¼"	6.6	8.8	11.0	13.2	15.4	17.6	19.7	21.9	24.1	26.3	28.5	30.7	32.9	35.1
2½"	7.3	9.8	12.2	14.6	17.1	19.5	21.9	24.4	26.8	29.2	31.7	34.1	36.6	39.0
2¾"	8.0	10.7	13.4	16.1	18.8	21.4	24.1	26.8	29.5	32.2	34.8	37.5	40.2	42.9
3"	8.8	11.7	14.6	17.6	20.4	23.4	26.3	29.2	32.2	35.1	38.0	40.9	43.8	46.8
3½"	10.2	13.7	17.1	20.5	23.9	27.3	30.7	34.2	37.5	40.9	44.4	47.8	52.2	54.6
4"	11.7	15.6	19.5	23.4	27.3	31.2	35.1	39.0	42.9	46.8	50.7	54.6	58.5	62.4
4½"	13.2	17.6	21.9	26.3	30.7	35.1	39.4	43.8	48.2	52.6	57.0	61.4	65.8	70.2
5"	14.6	19.5	24.4	29.3	34.1	39.0	43.8	48.7	53.6	58.4	63.4	68.2	73.2	78.0
5½"	16.1	21.4	26.8	32.2	37.6	42.9	48.2	53.6	59.0	64.3	69.7	75.0	80.4	85.8
6"	17.6	23.4	29.2	35.1	41.0	46.8	52.6	58.5	64.3	70.3	76.0	81.8	87.8	93.6
7"	20.4	27.3	34.1	41.0	47.8	54.6	61.4	68.2	75.0	82.0	88.7	95.5	102.	109.
8"	23.4	31.2	39.0	46.8	54.6	62.4	70.1	78.0	85.7	93.7	101.	109.	117.	125.
9"	26.4	35.1	43.9	52.7	61.4	70.2	78.9	87.7	96.5	105.	114.	123.	132.	140.
10"	28.2	39.0	48.8	59.0	68.2	78.0	87.7	97.5	107.	117.	127.	137.	146.	156.

L \ T	1 1/8"	1 1/4"	1 3/8"	1 1/2"	1 5/8"	1 3/4"	1 7/8"	2"	2 1/8"	2 1/4"	2 3/8"	2 1/2"	2 3/4"	3"
1"	17.6	19.5	21.5	23.4	25.4	27.3	29.3	31.2	33.2	35.2	37.0	39.0	43.0	46.8
1¼"	21.9	24.4	26.8	29.2	31.7	34.2	36.6	39.0	41.5	44.1	47.3	48.7	53.6	58.5
1½"	26.3	29.2	32.2	35.1	38.0	41.0	43.9	46.9	49.8	52.9	55.5	58.5	64.3	70.2
1¾"	30.7	34.1	37.6	40.9	44.4	47.8	51.2	54.7	58.2	61.7	64.8	68.2	75.0	81.9
2"	35.1	39.0	42.9	46.8	50.7	54.6	58.6	62.5	66.5	70.5	74.1	78.0	85.8	94.5
2¼"	39.5	43.8	48.3	52.6	57.0	61.4	65.9	70.3	74.6	79.4	83.3	87.7	96.5	105.
2½"	43.8	48.7	53.6	58.5	63.4	68.3	73.2	78.0	83.0	88.0	92.5	97.4	107.	117.
2¾"	47.3	53.6	59.0	64.3	69.6	75.1	80.5	85.9	91.3	97.0	102.	107.	118.	128.
3"	52.6	58.5	64.4	70.2	76.0	81.8	87.8	93.7	100.	106.	111.	117.	129.	141.
3½"	61.4	68.2	75.1	81.9	88.7	95.6	103.	109.	116.	124.	130.	136.	150.	164.
4"	70.2	78.0	85.8	93.5	102.	109.	117.	125.	134.	141.	148.	156.	172.	187.
4½"	79.0	87.7	96.5	105.	114.	123.	132.	141.	149.	159.	167.	175.	193.	211.
5"	87.7	97.5	107.	117.	127.	137.	146.	156.	166.	177.	185.	195.	215.	234.
5½"	96.6	107.	117.	129.	140.	150.	161.	172.	182.	194.	204.	214.	236.	257.
6"	106.	117.	129.	140.	152.	164.	176.	187.	199.	212.	222.	234.	258.	281.
7"	123.	137.	199.	164.	178.	191.	205.	218.	232.	247.	259.	273.	300.	327.
8"	141.	156.	172.	187.	203.	218.	236.	250.	266.	282.	296.	312.	343.	374.
9"	158.	176.	194.	210.	228.	246.	264.	281.	298.	318.	333.	351.	386.	421.
10"	176.	195.	215.	234.	254.	273.	293.	312.	332.	353.	370.	390.	430.	468.

Allowable Eccentric Longitudinal Loads on Fillet Welds

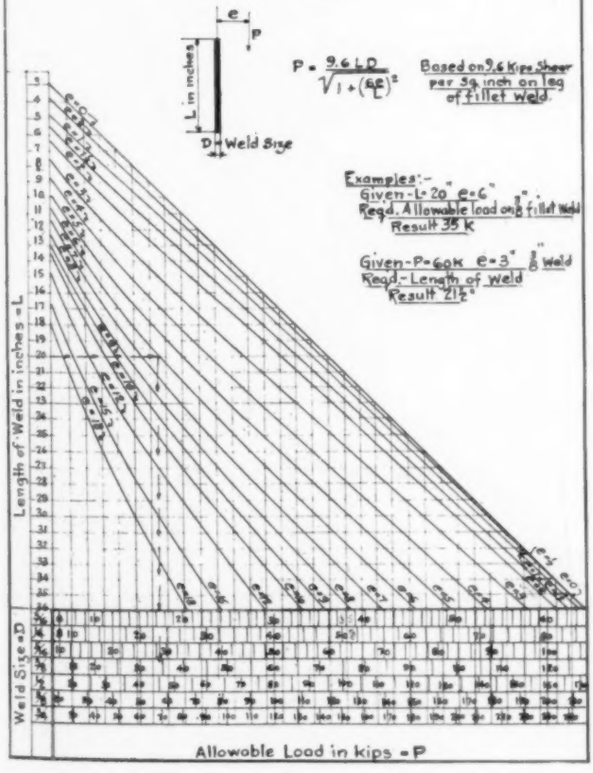


Fig. 12

Allowable Eccentric Longitudinal Loads On Short Fillet Welds.

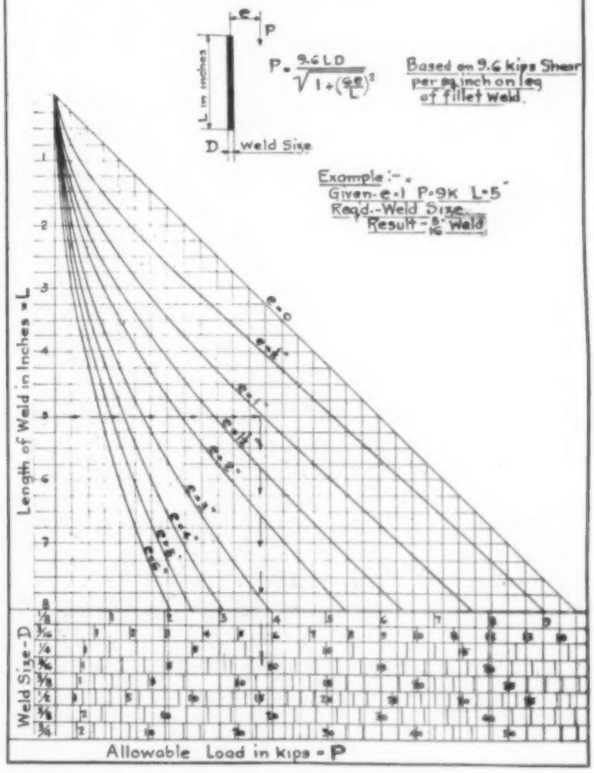


Fig. 13

Fig. 14

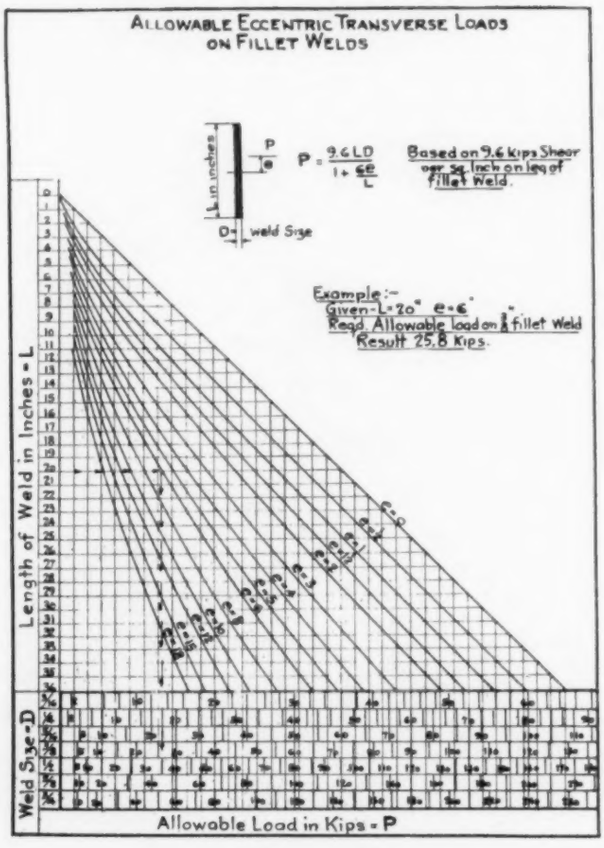

ALLOWABLE ECCENTRIC TRANSVERSE LOADS ON FILLET WELDS
P
e in inches
D = weld Size
P = 9.6LD / (1 + 6e/L)
Based on 9.6 Kips Shear per Sq. Inch on leg of Fillet Weld.
Example:-
Given-L=20" e=6"
Read Allowable load on 3/8 fillet Weld
Result 25.8 Kips.
Length of Weld in Inches = L
Weld Size = D
Allowable Load in Kips = P

Fig. 15

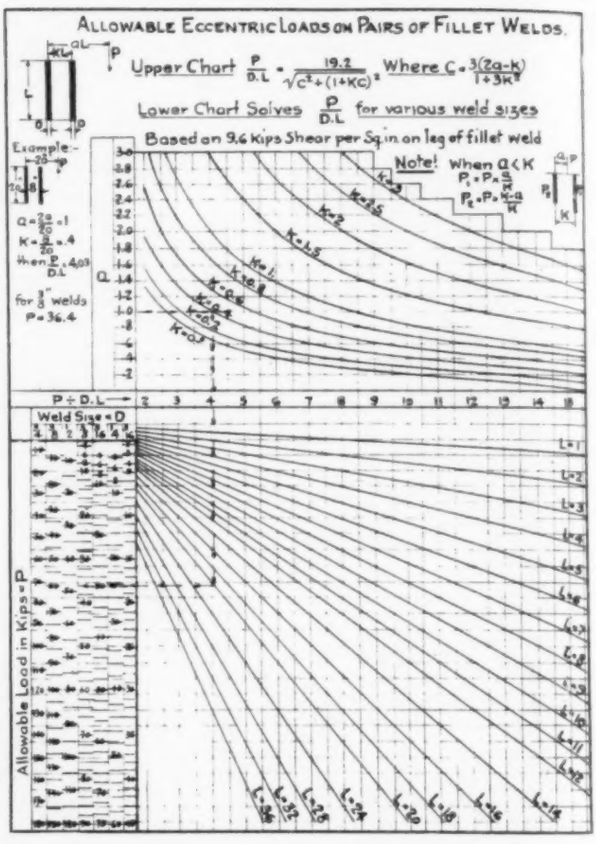

ALLOWABLE ECCENTRIC LOADS ON PAIRS OF FILLET WELDS.
Upper Chart P/D.L = 19.2 / √(C² + (1+KC)²) Where C = 3(2a-K)/(1+3K²)
Lower Chart Solves P/D.L for various weld sizes
Based on 9.6 Kips Shear per Sq.in on leg of fillet weld
Note! When a < K
Example-
Q = 2a/L = .1
K = K/L = .4
then P/D.L = 4.03
for 3/8" welds
P = 36.4
P ÷ D.L
Weld Size = D
Allowable Load in Kips = P

Fig. 16

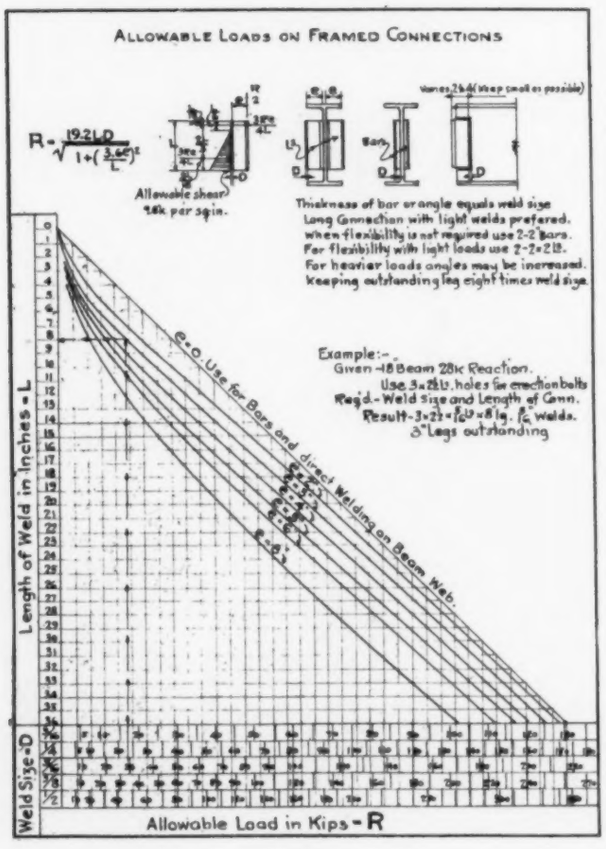

ALLOWABLE LOADS ON FRAMED CONNECTIONS
R = 19.2LD / √(1 + (3.6e/L)²)
Allowable shear 9.6k per sq.in.
Thickness of bar or angle equals weld size
Long Connection with light welds preferred.
when flexibility is not required use 2-2" Bars.
For flexibility with light loads use 2-2x2½.
For heavier loads angles may be increased.
Keeping outstanding leg eight times weld size.
Example:-
Given -18 Beam 28k Reaction.
Use 3-7/8" holes for erection bolts
Reqd.- Weld Size and Length of Conn.
Result-3-2½x5/16x8" lg. fillet welds.
5/16" Legs outstanding
e=0 Use for Bars and direct Welding on Beam Web.
Length of Weld in Inches = L
Weld Size = D
Allowable Load in Kips = R

Fig. 17

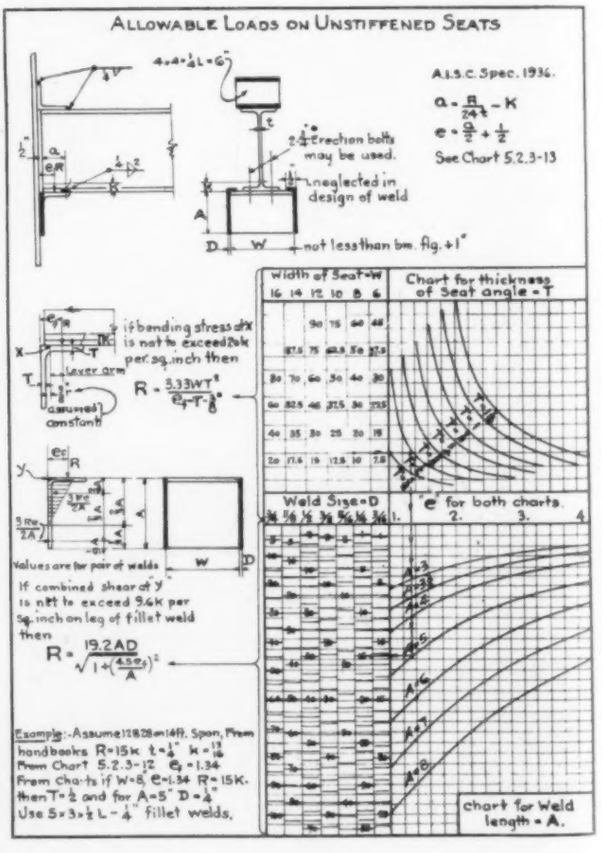

ALLOWABLE LOADS ON UNSTIFFENED SEATS
A.I.S.C. Spec. 1936.
a = R/24t - K
e = a/2 + 1/2
See Chart 5.2.3-13
2-7/8" Erection bolts may be used.
neglected in design of weld
not less than bm. flg. +1"
if bending stress at X is not to exceed 20k per sq.inch then
R = 3.33WT² / (e - T - 1/8)
assumed constant
Lever arm
If combined shear at y is not to exceed 9.6K per Sq. inch on leg of fillet weld then
R = 19.2AD / √(1 + (4.5e/A)²)
Values are for pair of welds
Example:-Assume 12&28 on 14ft. Span, From handbooks R=15K t=1/4" K=13/16
From Chart 5.2.3-12 e=1.34
From Charts if W=8, e=1.34 R=15K.
then T=1/2 and for A=5" D=4"
Use 5x3x1/2 L - 1/4" fillet welds.
Width of Seat = W
Chart for thickness of Seat angle = T
"e" for both charts.
Weld Size = D
chart for Weld length = A.

Fig. 18

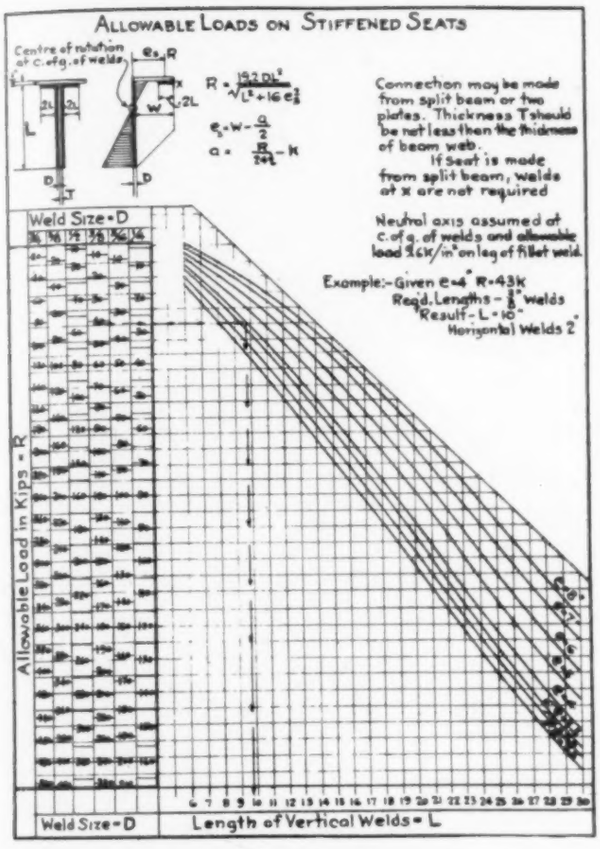
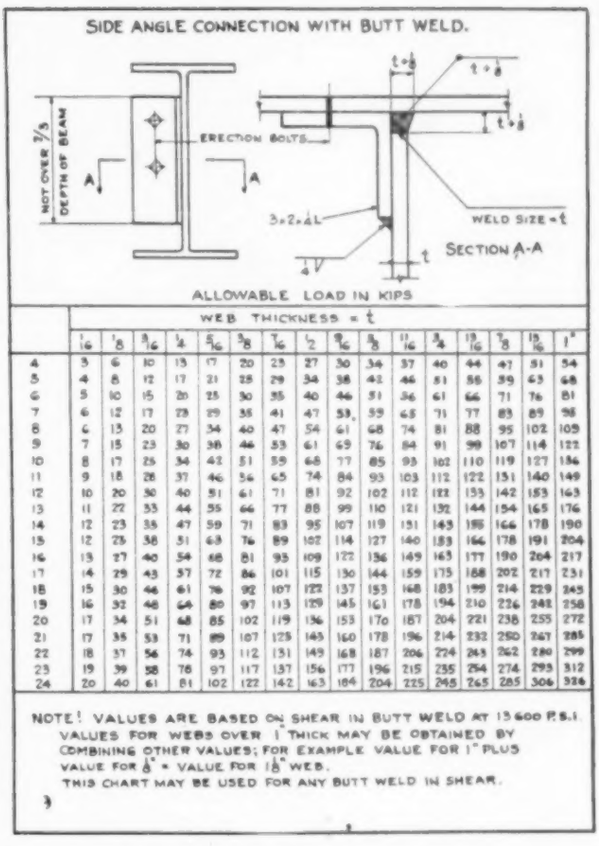

ALLOWABLE LOADS ON STIFFENED SEATS
Centre of rotation of C. of g. of welds
$R = \frac{192\,D L^2}{\sqrt{L^2+16\,e_2^2}}$
$e_2 = W - \frac{a}{2}$
$a = \frac{2R}{14L} - K$
Connection may be made from split beam or two plates. Thickness T should be not less than the thickness of beam web.
If Seat is made from split beam, welds at X are not required
Neutral axis assumed at C. of g. of welds and allowable load 9.6K/in² on leg of fillet weld.
Example:- Given e=4" R=43K
Reqd. Lengths - ⅜" Welds
Result - L = 10"
Horizontal Welds 2"
Weld Size = D
Allowable Load in Kips = R
Weld Size - D
Length of Vertical Welds = L

Fig. 19

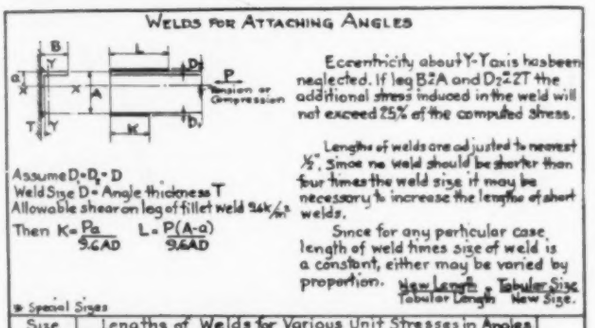


ALLOWABLE LOAD IN KIPS

	WEB THICKNESS = t														
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1"
4	3	6	10	13	17	20	23	27	30	34	37	40	44	47	51	54
5	4	8	12	17	21	25	29	34	38	42	46	51	55	59	63	68
6	5	10	15	20	25	30	35	40	46	51	56	61	66	71	76	81
7	6	12	17	23	29	35	41	47	53	59	65	71	77	83	89	95
8	6	13	20	27	34	40	47	54	61	68	74	81	88	95	102	109
9	7	15	23	30	38	46	53	61	69	76	84	91	99	107	114	122
10	8	17	25	34	42	51	59	68	77	85	93	102	110	119	127	136
11	9	18	28	37	46	56	65	74	84	93	103	112	122	131	140	149
12	10	20	30	40	51	61	71	81	92	102	112	122	133	142	153	163
13	11	22	33	44	55	66	77	88	99	110	121	132	144	154	165	176
14	12	23	35	47	59	71	83	95	107	119	131	143	155	166	178	190
15	12	25	38	51	63	76	89	102	114	127	140	153	166	178	191	204
16	13	27	40	54	68	81	95	109	122	136	149	163	177	190	204	217
17	14	29	43	57	72	86	101	115	130	144	159	175	188	202	217	231
18	15	30	46	61	76	92	107	122	137	153	168	183	199	214	229	245
19	16	32	48	64	80	97	113	129	145	161	178	194	210	226	242	258
20	17	34	51	68	85	102	119	136	153	170	187	204	221	238	255	272
21	17	35	53	71	89	107	125	143	160	178	196	214	232	250	267	285
22	18	37	56	74	93	112	131	149	168	187	206	224	243	262	280	299
23	19	39	58	78	97	117	137	156	177	196	215	235	254	274	293	312
24	20	40	61	81	102	122	142	163	184	204	225	245	265	285	306	326

NOTE! VALUES ARE BASED ON SHEAR IN BUTT WELD AT 13 600 P.S.I. VALUES FOR WEBS OVER 1" THICK MAY BE OBTAINED BY COMBINING OTHER VALUES; FOR EXAMPLE VALUE FOR 1" PLUS VALUE FOR ⅛" = VALUE FOR 1⅛" WEB.
THIS CHART MAY BE USED FOR ANY BUTT WELD IN SHEAR.

Fig. 20

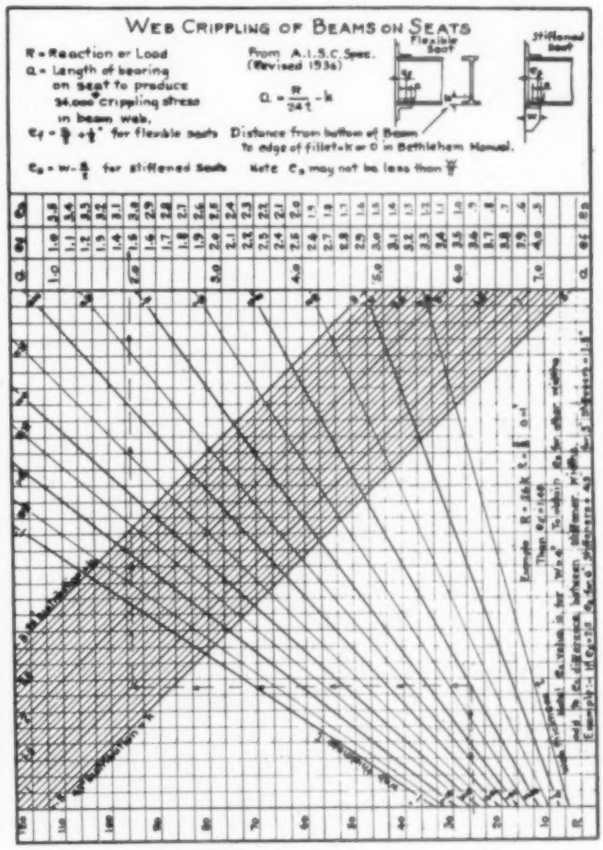

WELDS FOR ATTACHING ANGLES
Assume D₁ = D₂ = D
Weld Size D = Angle thickness T
Allowable shear on leg of fillet weld 9.6K/in²
Then $K = \frac{Pa}{9.6AD}$ $L = \frac{P(A-a)}{9.6AD}$
Eccentricity about Y-Y axis has been neglected. If leg B2A and D2 2.2T the additional stress induced in the weld will not exceed 25% of the computed stress.
Lengths of welds are adjusted to nearest ½". Since no weld should be shorter than four times the weld size it may be necessary to increase the lengths of short welds.
Since for any particular case length of weld times size of weld is a constant, either may be varied by proportion. New Length = Tabular Length × Tabular Size / New Size.
Tension or Compression

* Special Sizes

Size of Angle	Lengths of Welds for Various Unit Stresses in Angles																			
	22.5K/in²		19.5K/in²		17.5K/in²		16K/in²		15K/in²		14K/in²		13K/in²		12K/in²		11K/in²		10K/in²	
	K	L	K	L	K	L	K	L	K	L	K	L	K	L	K	L	K	L	K	L
8×8	9.0	23.5	8.5	22.0	8.0	21.0	7.5	20.0	7.0	18.5	7.0	17.5	6.0	16.5	5.0	15.0	5.5	14.0	5.0	13.0	4.5	12.0
8×6	9.0	20.0	8.0	19.0	8.0	17.5	7.5	16.5	7.0	15.5	6.5	15.0	6.0	14.0	5.5	13.0	5.0	12.0	5.0	10.5	4.0	10.0
8×4	8.5	15.5	8.0	15.0	7.5	14.0	7.5	13.0	7.0	12.5	6.5	11.5	6.0	11.0	5.5	10.0	5.0	9.5	4.5	8.5	4.0	8.0
7×4	7.5	14.5	7.0	14.0	7.0	13.0	6.5	12.5	6.0	12.0	6.0	11.0	5.5	10.0	5.0	9.5	4.5	8.0	4.0	7.0
6×6	6.5	17.5	6.5	17.0	6.0	16.0	6.0	15.0	5.5	14.0	5.5	13.0	5.0	12.0	4.5	11.5	4.0	11.0	4.0	10.5	3.5	8.5
6×4	6.5	14.0	6.5	13.0	6.0	12.5	5.5	11.5	5.0	11.0	5.0	10.0	4.5	9.5	4.5	8.5	4.0	8.0	3.5	7.5	3.0	7.0
* 6×3½	6.5	12.5	6.0	12.0	6.0	11.0	5.5	10.5	5.0	10.5	5.0	9.5	4.5	9.0	4.5	8.0	4.0	7.5	3.5	7.0	3.0	6.5
5×5	5.5	14.5	5.0	14.0	5.0	13.0	5.0	12.5	4.5	11.5	4.0	11.0	4.0	10.0	3.5	9.5	3.5	9.5	3.0	8.0	3.0	7.0
5×3½	5.5	11.5	5.0	11.0	5.0	10.5	4.5	10.0	4.5	9.0	4.0	9.0	4.0	8.0	3.5	7.5	3.5	7.0	3.0	6.5	3.0	5.5
* 5×3	5.5	10.5	5.0	10.0	5.0	9.5	4.5	9.0	4.5	8.5	4.0	8.0	4.0	7.5	3.5	7.0	3.0	6.5	3.0	6.0	3.0	5.0
4×4	4.5	12.0	4.5	11.0	4.0	10.5	4.0	10.0	3.5	9.5	3.5	8.5	3.5	8.0	3.0	7.5	3.0	7.0	2.5	6.5	2.5	5.5
4×3½	4.5	10.5	4.5	10.0	4.0	9.5	4.0	9.0	3.5	8.5	3.5	8.0	3.0	7.5	3.0	6.5	3.0	6.0	2.5	6.0	2.5	5.0
4×3	4.5	9.6	4.5	9.0	4.0	8.5	4.0	8.0	3.5	8.0	3.5	7.5	3.0	7.0	3.0	6.5	3.0	5.5	2.5	5.5	2.5	4.5
3½×3½	4.0	10.0	4.0	9.5	3.5	9.5	3.5	8.5	3.0	8.5	3.0	7.5	3.0	7.0	2.5	6.5	2.5	6.0	2.5	5.5	2.0	5.0
3½×3	4.0	9.0	4.0	8.5	3.5	8.5	3.5	7.5	3.0	7.5	3.0	7.0	3.0	6.5	2.5	6.0	2.5	5.5	2.0	5.0	2.0	4.5
* 3½×2½	4.0	8.0	4.0	7.5	3.5	7.5	3.0	7.0	3.0	7.0	3.0	6.0	3.0	5.5	2.5	5.5	2.5	5.0	2.0	4.5	2.0	4.0
3×3	3.5	8.5	3.5	8.0	3.0	8.0	3.0	7.0	3.0	7.0	2.5	6.5	2.5	6.0	2.0	6.0	2.0	5.5	2.0	4.5	1.5	4.5
3×2½	3.5	7.5	3.5	7.0	3.0	7.0	3.0	6.5	3.0	6.0	2.5	6.0	2.5	5.0	2.0	5.0	2.0	4.5	2.0	4.0	1.5	4.0
* 3×2	3.5	6.5	3.0	7.0	3.0	6.0	3.0	5.5	2.5	5.5	2.5	5.0	2.0	5.0	2.0	4.5	2.0	4.0	2.0	3.5	1.5	3.5
2½×2½	3.0	7.5	3.0	7.0	2.5	6.5	2.5	6.0	2.5	5.5	2.0	5.5	2.0	5.0	2.0	4.5	1.5	4.5	1.5	4.0	1.5	3.5
2½×2	3.0	6.5	3.0	6.0	2.5	6.0	2.5	5.0	2.5	5.0	2.0	5.0	2.0	4.5	2.0	4.0	1.5	4.0	1.5	3.5	1.5	3.0
2×2	2.5	5.5	2.5	5.5	2.0	5.5	2.0	5.0	2.0	4.5	1.5	4.5	2.0	4.0	1.5	4.0	1.5	3.5	1.5	3.0	1.0	3.0
2×1½	2.5	4.5	2.5	4.5	2.0	4.5	2.0	4.0	2.0	4.0	2.0	3.5	1.5	3.5	1.5	3.0	1.5	3.0	1.5	2.5	1.0	2.5
1¾×1¾	2.0	4.0	2.0	4.0	1.5	4.0	1.5	3.5	1.5	3.5	1.5	3.0	1.5	3.0	1.5	2.5	1.5	2.5	1.0	2.5	1.0	2.0
1½×1½	1.5	3.5	1.5	3.5	1.5	3.5	1.5	3.0	1.5	3.0	1.5	2.5	1.5	2.0	1.5	2.0	1.0	2.0	1.0	2.0	1.0	2.0
1½×1	1.5	3.0	1.5	3.0	1.5	2.5	1.5	2.5	1.0	2.5	1.0	2.5	1.0	2.0	1.0	2.0	1.0	2.0	1.0	1.5	1.0	1.5
1¼×1¼	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	1.5	1.0	1.5	1.0	1.5	1.0	1.5	0.5	1.5	0.5	1.5	0.5	1.5
1×1	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	0.5	0.5	0.5

K and L for any other unit stresses may be obtained by proportion or interpolation.

Fig. 21


WEB CRIPPLING OF BEAMS ON SEATS
R = Reaction or Load
a = Length of bearing on seat to produce 24,000 crippling stress in beam web.
From A.I.S.C. Spec. (Revised 1936)
$a = \frac{R}{24\,t} - k$
$e_f = \frac{k}{2} + \frac{1}{8}$" for flexible seats
$e_s = w - \frac{k}{2}$ for stiffened seats
Distance from button of Beam to edge of fillet = k or 0 in Bethlehem Manual.
Note: e_s may not be less than $\frac{w}{2}$
Flexible Seat
Stiffened Seat

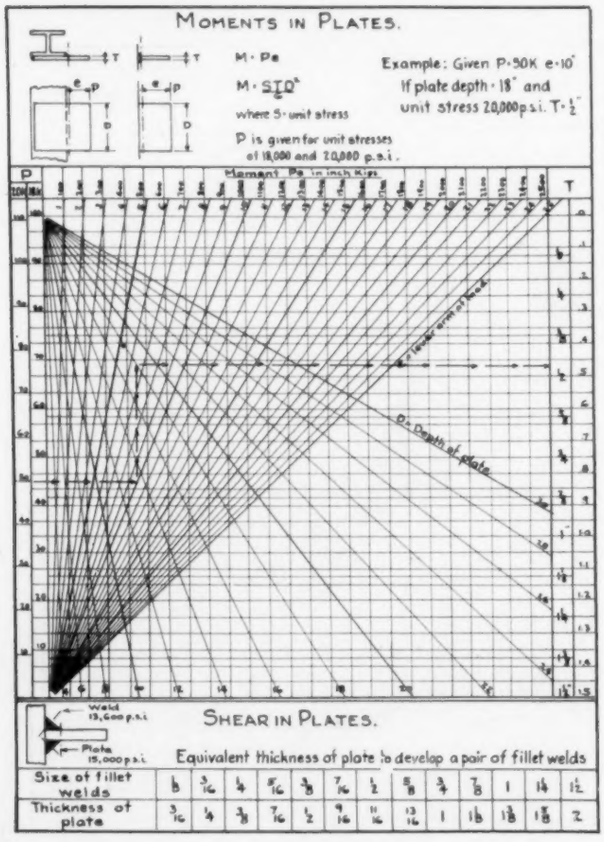

MOMENTS IN PLATES.
M = Pe
M = SID²
where S = unit stress
P is given for unit stresses of 18,000 and 20,000 p.s.i.
Example: Given P = 50K e = 10"
If plate depth = 18" and
unit stress 20,000 p.s.i. T = 1/2"
Moment Pe in inch Kips
P
T
D = Depth of plate
SHEAR IN PLATES.
Weld 13,600 p.s.i.
Plate 15,000 p.s.i.
Equivalent thickness of plate to develop a pair of fillet welds
Size of fillet welds
Thickness of plate

Fig. 22

centricity e_f is determined for any case on Fig. 21 and used for determining angle size and welding on Fig. 17. Similarly, for stiffened seats e_s is obtained from Fig. 21 and used on Fig. 18 to design the connection.

Figure 20 is self-explanatory, and so is Fig. 19 also. This single side angle connection or any similar butt-welded connection where there is no flexibility should not be used for bridge stringers, crane girder connections or any similar connection subject to a large number of stress reversals as the flexibility is obtained by deformation of the beam web and it is not known at this time what value the beam web possesses under repeated loadings. Figure 22 is self-explanatory.

The formula used on Fig. 15 was devised by Mr. Gilbert D. Fish about ten years ago and adapted to chart form by the author. All other formulas are simple derivations from the laws of mechanics, assuming that a fillet weld acts only in shear and that all loads, however applied, may be resolved into a single shear plane of unit width. The assumptions made in Fig. 16, although slightly empirical, are in fair agreement with similar assumptions of Fish and Priest. The Theory of Design of the Flexible Seat, Fig. 17, was covered fully by the author in an article in the AMERICAN WELDING SOCIETY JOURNAL (June 1935).

For certain types of structures where a high degree of skill in welded design is necessary to obtain an economical structure, the average structural engineer should call in a consultant. For tier buildings and the simpler types of mill buildings, however, the structural engineer may safely design for welding, if he will design the main material only, and leave to the fabricator the design of the details. In the case of trusses, he should furnish only a truss diagram with stresses indicated and permit the fabricator to select the truss material. Of course, all reactions and moments should be given as an aid to the detailer. When depending upon the fabricator for design of the details, it would be well to specify that he show satisfactory proof of his ability to fabricate welded structures and design welded details.

It is common practice for some engineers to specify $^3/_8$-inch minimum welds; railroad engineers seem to favor $^1/_2$-inch minimum. The correct size of weld is a matter of intelligent design and should not be determined by arbitrary specification. Good strength welds are being used today as small as $^3/_{16}$ inch and for structural work $^1/_4$ inch is about the most common size. It does not seem to be known to structural engineers that for wide flange sections, under 18-inch depth, only the heavier weights have flanges or webs thick enough to permit the use of $^3/_8$-inch fillets and that joists and small sizes of channels and beams can accommodate no larger than $^3/_{16}$-inch fillets. This is shown on Chart, Fig. 23.

Use of $^3/_{16}$-inch and $^1/_4$-inch welds on heavy material may result in excessive quench and brittle welds; these light welds should, therefore, not be used indiscriminately by those with little or no welding experience. Again, this is a question of engineering design and should be handled by one experienced in the art. Too heavy a weld is wasteful and produces excessive distortion; too light a weld may crack before it fully cools.

For welding specifications, merely require that all designs and welding conform to the AMERICAN WELDING SOCIETY Specification applicable to the particular structure. One who is not thoroughly experienced and in constant touch with developments in welded construction should not attempt to write his own specifications, as a requirement which may have been good practice yesterday may prevent obtaining the best job today.

FLANGE THICKNESSES FOR WELDING

MAXIMUM WELD SIZE

3/16	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1"
3 C	4 B 5 10	4 B 5 13	6 BL 16	6 H 30	6 H 41	8 H 58	8 H 67	10 H 100
3 I	5 I	5 B 5	6 H 23	8 H 35	8 H 48	10 H 72	10 H 89	10 H 120
4 C	6 I	6 H 20	6 H 27	8 H 40	10 H 60	10 H 77	12 H 92	12 H 136
4 I	6 BL 12	8 BL 15	8 G 24	10 G 41	10 H 66	12 H 85	12 H 99	14 H 142
4 B 5 7.5	6 B 5 18	8 B 21	8 G 27	10 G 45	12 G 64	14 G 74	12 H 106	14 H 150
5 C	6 B 10	10 I	8 H 31	10 H 49	12 H 72	14 H 84	14 H 119	24 G 160
6 C	7 B 12	10 BL 17	8 H 33	10 H 54	12 H 79	14 H 103	14 H 127	27 G 177
6 B 5 15.5	7 C	10 B 23	10 BL 19	12 I 40.8	14 G 53	14 H 111	16 G 114	30 G 190
6 BJ	7 I	12 BL 19	10 B 26	12 I 45	14 G 58	16 G 78	18 G 114	30 G 200
8 BJ	8 C	12 B 28	10 B 29	12 I 50	14 G 61	16 G 96	18 G 124	33 G 210
10 BJ	8 I	14 B 30	10 G 33	12 I 55	14 G 68	16 G 105	21 B 96	33 G 220
12 BJ	8 BL 13	16 B 36	10 G 37	12 B 36	14 G 78	18 B 77	21 B 103	36 B 170
	8 B 17		12 I 31.8	12 G 40	14 H 87	18 B 85	21 G 132	36 B 182
	8 B 19		12 I 35	12 G 45	14 H 95	18 G 105	21 G 142	36 G 230
	9 C		12 BL 22	12 G 53	16 G 64	21 B 89	24 G 150	1 8
	10 C		12 B 32	12 G 58	16 G 71	21 G 122	27 G 154	10 H 112
	10 BL 15		14 B 34	12 H 65	16 G 88	24 I 105.9	27 G 163	12 H 133
	10 B 21		14 B 38	14 B 42	18 B 70	24 I 110	30 B 132	14 H 158
	12 C		15 C	14 G 43	18 G 96	24 I 115	30 G 172	14 H 167
	12 BL 16.5		15 I 42.9	14 G 48	20 I 81.4	24 I 120	30 G 180	36 G 210
	12 B 25		15 I 45	15 I 60.8	20 I 85	24 G 94	33 B 141	36 B 194
			15 I 50	15 I 65	20 I 90	24 G 110	33 B 152	36 G 240
			15 I 55	15 I 90	20 I 95	24 G 120	33 G 200	36 G 250
			16 B 40	15 I 75	20 I 100	24 G 130	36 B 160	1 4
			18 B 47	16 B 45	21 B 73	24 G 140		10 H 124
				16 B 50	21 B 82	27 B 106		12 H 147
				16 B 58	21 G 112	27 B 114		14 H 176
				18 C	24 I 79.9	27 G 145		14 H 184
				18 I	24 I 85	30 B 116		33 G 240
				18 B 50	24 I 90	30 B 124		36 G 260
				18 B 55	24 I 95	30 B 132		1 2
				18 B 64	24 I 100	36 B 150		10 H 136
				20 I 65.4	24 B 80			12 H 161
				20 I 70	24 B 87			14 H 193
				20 I 75	24 G 100			14 H 202
				21 B 59	27 B 98			36 G 280
				21 B 63	30 B 108			1 2
				21 B 68	33 B 125			12 H 176
				24 B 74				14 H 211
				27 B 91				36 G 300

Fig. 23

Welding Speeds Are Increased More Than 25 Per Cent with the 4-Flame Bell-Hole Tip

SPEEDING THE CONSTRUCTION OF Overland Pipe Lines

By GEORGE SYKES†

HIGHER quality welds, increased speeds of 25 per cent or more, and a reduction in gas consumption of at least 25 per cent are now made possible by two outstanding developments in the welding of overland pipe lines by oxyacetylene welding. These two developments are: (1) new 4- and 6-flame tips for position welds and rolling welds, respectively, and (2) a new low-alloy steel welding rod. Following a brief review of the factors leading to present-day pipe line construction methods, the new tips and rod will be described in some detail, together with recommended procedures for their use, and the results obtained on a number of recently completed lines.

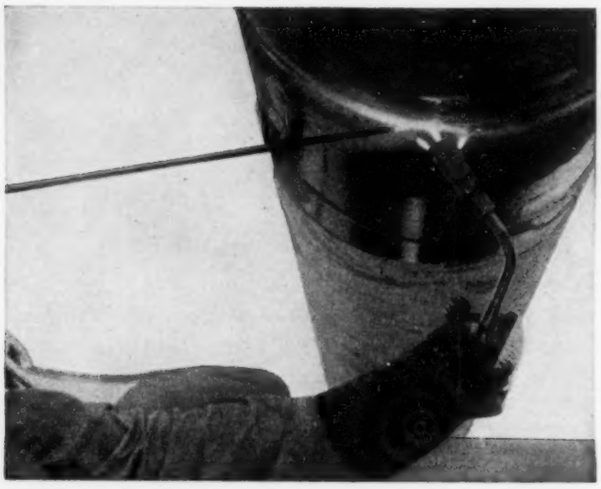
DEVELOPMENT OF LINDEWELDING

Although the oxyacetylene welding of pipe lines dates back to before the World War, it was not until 1930 that the technique now widely employed was first introduced. This process, involved the use of backhand welding, a special flame adjustment and a special welding rod. Using this technique, welds were made in half the time and at half the cost of methods formerly used.

This was followed in 1934 by the development of a 3-flame tip which was designed especially for making rolling welds and which further speeded the gas welding of pipe lines. In addition to the main welding flame, this tip had two smaller auxiliary flames positioned so as to preheat the vee directly ahead of the point of welding. Savings of more than 25 per cent in rods and gases and of 30 per cent or more in welding time were effected by the use of this multi-flame tip, as compared with single-flame welding.

The success of the 3-flame tip led quite naturally to extensive investigation of the possibilities of other multi-flame tips for making position or bell-hole welds, as well as for making rolling welds. This investigation, spurred by the recent popularity of the all-bell-hole method of construction, resulted in the development of two new

† The Linde Air Products Company.



Making a Bell-Hole Weld in an Overhead Position with the 4-Flame Tip

tips—a 4-flame tip for position welds and a 6-flame tip for rolling welds.

ALL-BELL-HOLE METHOD

The all-bell-hole method consists in assembling the line, a length at a time, and making all welds in position, that is, making them as bell-hole welds (*Oxy-Acetylene Tips*, November 1936). What it really amounts to is the elimination of the usual line-up and firing-line gangs, with the bending or tie-in gang handling sections 40 ft. long instead of the usual 200 ft. This method also eliminates dollies and other devices for rolling pipe.

The procedure usually followed is to line up the pipe on skids over the ditch, after which the joints are tack-welded and then welded without turning the pipe. Besides the tacker, from three to six or more operators do the bell-hole welding, the number depending on the speed with which the pipe is lined up.

Variations of the bell-hole method included the so-called "stap-on" and "stove-pipe" methods (*Oxy-Acetylene Tips*, February 1937) which are commonly used on short lines. Also, there has been developed during the past year a new procedure known as the "one-third roll" method which has been used with considerable success on a number of recently completed lines. This method will be discussed later in connection with the construction of a 16-inch gas line.

In spite of its inherent advantage of simplified organization, the all-bell-hole method requires somewhat more time for making the joint than is required for making a rolling weld. However, with the introduction of the new 4-flame tip and welding rod, it is now possible to produce a bell-hole weld in about the same time that it formerly took to make a rolling weld with a 3-flame tip. For example, on 16-inch diameter pipe with $^1/_4$-inch wall thickness, an operator can complete one of these position welds in 8 to 12 min. This is an average of about 5 linear inch of welding a minute, and it is readily apparent that at this speed, the advantages and savings resulting from the all-bell-hole method of construction can now be fully realized.

FOUR-FLAME TIP FOR POSITION WELDING

In addition to the main welding flame, the 4-flame tip provides two flames for preheating the vee and a fourth flame for preheating the rod. The jet for the rod preheat is so located that the operator has control of the amount of rod preheated and melted regardless of the point of welding. The two flames for preheating the vee are positioned similarly to those in the 3-flame tip.

The 4-flame tip is designed in two sizes—the smaller, for pipe wall thicknesses from $^1/_4$ inch to $^9/_{32}$ inch, and the larger, for thicknesses from $^5/_{16}$ inch to $^3/_8$ inch.

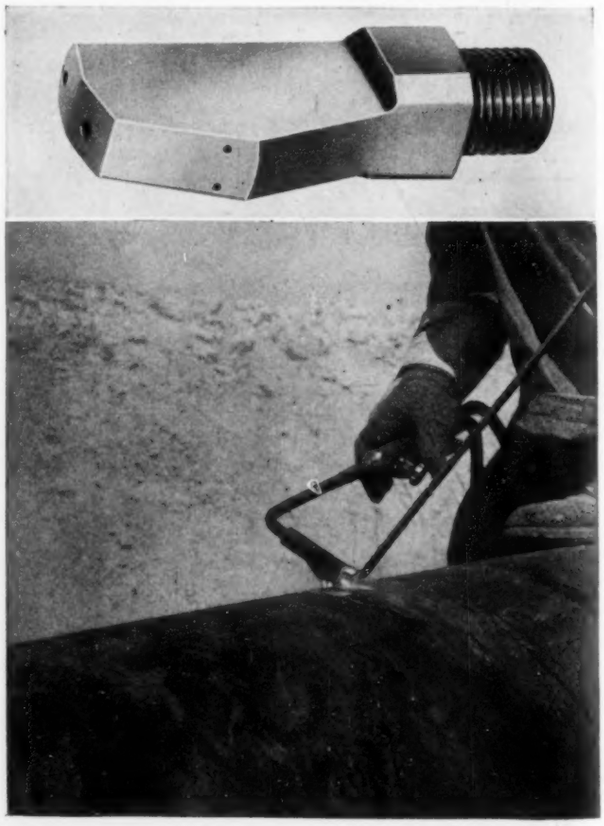
WELDING TECHNIQUE—FOUR-FLAME TIP

No special technique is required when making position welds with the 4-flame tip. The manipulation of the blow-pipe is essentially the same as that employed when welding with either a single-flame or 3-flame tip. Operators proficient in the special welding technique will have no difficulty using the 4-flame tip, although they will find it necessary to proceed at a faster rate.

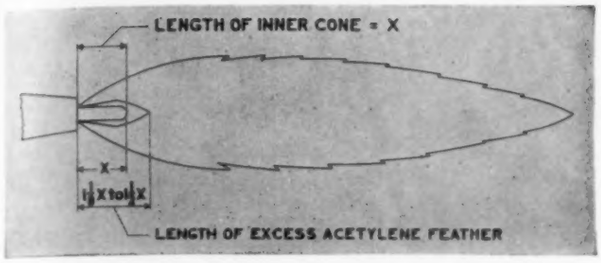
The flames should be adjusted with enough excess acetylene to give a feather about $1^1/_2$ times the length of the inner cone. If this adjustment is made with the main welding flame as a guide, the other flames will be correct.

To position the flame correctly, the blowpipe should be held with the tip parallel to the line of weld and with the welding flame pointing to the base of the vee. Then, with the welding flame maintained in this position and with its inner cone barely out of contact with the metal, the blow-pipe should be rotated in the plane of the weld until the inner cones of the vee preheat flames are just above the metal. This automatically brings the rod preheat flame into correct position.

In welding, practically all the rod and blowpipe movement is confined to a back-and-forth or accordion motion



The New 4-Flame Tip for Position Welding Incorporates Two Flames for the Vee Preheat, One for the Rod Preheat and One for Actual Welding



The Excess Acetylene Feather Should Be from 1⅛ to 1½ Times the Length of the Inner Cone for This New Method of Welding

along the line of weld, with little or no motion transverse to the weld. Although actual melting of the rod is completed by the main welding flame, the auxiliary flame normally preheats the rod sufficiently to develop a visible red. The rate at which the rod is melted can be controlled by varying this preheating action through movement of either the rod or the blowpipe.

After the weld is under way, both hands should move in the accordion motion just mentioned—one moving the blowpipe so as to prepare the vee and melt the rod alternately, and the other moving the rod in the puddle so as to direct the flow of molten metal. Since less of the welding flame heat is required to melt the rod, more can be used to prepare the vee, thus increasing the welding speed.

The technique is essentially the same for various positions around the pipe except that the rate at which the rod is melted is changed as necessary. The procedure is to start at the top of the joint and proceed continuously around to the lowest point, then start again at the top and proceed down the remaining half of the weld.

WELDING SPEEDS—FOUR-FLAME TIP

The figures for welding speeds and material consumption shown in Table 1 are typical of what may be expected on a well organized pipe line job using the all-bell-hole method of construction and the 4-flame tips.

As a basis for comparison with previous techniques, data selected from field records shown that 8-inch diameter pipe with a ⅜-inch wall thickness is welded in approximately 8 min. with a 4-flame tip. With this tip, joints in 16-inch diameter pipe with a wall thickness of 5/16 inch required only about 12 min. to complete.

With the greater welding speeds now possible, the construction of overland pipe lines on scheduled time is more than ever dependent upon efficient organization. The work of the various gangs must be coordinated so that the entire organization progresses efficiently.

Table 1—Data for Making Position Welds Using the Four-Flame Tip

Pipe Diameter, In.	Wall Thickness, In.	Included Angle, Deg.	Rod Per Weld, Lb.	Oxygen Per Weld, Cu. Ft.	Time Per Weld Min.
6	0.250	60	0.38	8	4
8	0.250	60	0.45	11½	6
8	0.375	50	0.87	16	8
12	0.250	60	0.80	17	9
12	0.312	50	0.90	19	10
16	0.250	60	1.00	21	11
20	0.250	60	1.25	26	13

NOTE: Acetylene consumption is about 3 per cent more than oxygen.

SIX-FLAME TIP FOR ROLLING WELDS

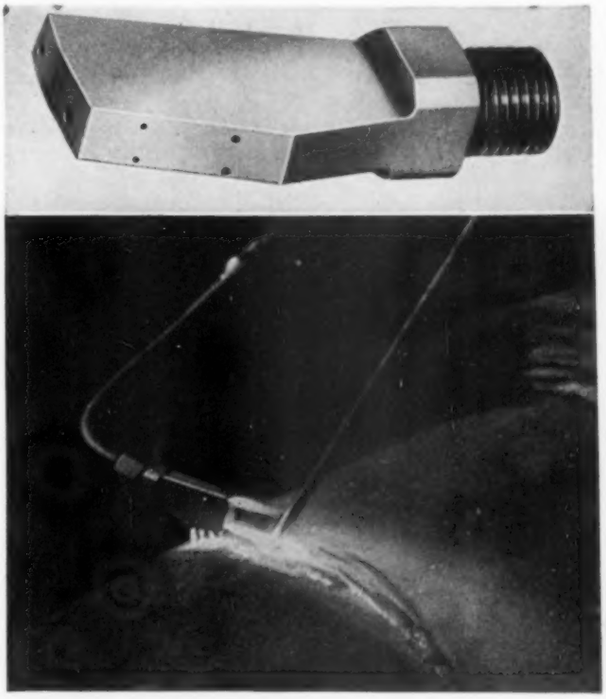
The 6-flame tip is similar in design to the 4-flame tip except that it has two additional vee preheat flames. Four flames of this tip preheat the walls of the pipe, a fifth flame preheats the rod and a sixth flame does the actual welding. This tip is designed for pipe diameters above 6 inches and is available in two sizes—the first, for pipe wall thicknesses from ¼ inch to 9/32 inch, and the second, for thicknesses from 5/16 inch to ⅜ inch.

WELDING TECHNIQUE—SIX-FLAME TIP

The technique described for the 4-flame tip also applies in its essentials to the 6-flame tip, except for modifications brought about by the peculiarities of each type of joint. Since all welding on a rotated pipe joint is performed in the same position, manipulation need not be adapted to changing conditions. In addition, the speed at which a rotated pipe joint can be welded, particularly on smaller diameters, is particularly dependent on the time required for the puddle to solidify, since solidification must occur before the puddle has passed beyond a horizontal position.

WELDING SPEEDS—SIX-FLAME TIP

Because of the more effective application of heat, the 6-flame tip increases the speed on rolling welds over that for 3-flame welding by 35 to 70 per cent, depending on the size of the pipe. As compared with single-flame welding, the speed of welding with the 6-flame tip is more than doubled. For example, results from the field show that the 6-flame tip averages somewhat less than 5 min. per weld on 8-inch pipe with ¼-inch wall thickness, and approximately 8 min. per joint on 16-inch diameter pipe with a wall thickness of ¼ inch.



The 6-Flame Tip for Making Rolling Welds Is Similar in Design to the 4-Flame Tip Except That It Has Two Additional Flames for the Vee Preheat

Lining-Up and Tack-Welding a Line for Bell-Hole Welding

Table 2 lists the material consumption and speeds for various sizes of pipe using the 6-flame tip on rotating welds.

Table 2—Data for Making Rolling Welds Using the Six-Flame Tip

Pipe Diameter, In.	Wall Thickness, In.	Included Angle, Deg.	Rod per Weld, Lb.	Oxygen per Weld, Cu. Ft.	Time per Weld, Min.
6	0.250	60	0.34	5½	3½
6	0.312	60	0.50	6½	3¾
8	0.250	60	0.44	7	4
8	0.375	60	0.80	12¼	6
10	0.250	60	0.52	8	5¼
10	0.375	60	0.98	16½	8
12	0.250	60	0.65	9½	5½
12	0.375	60	1.08	20½	10
16	0.250	60	0.84	13	7½
16	0.375	60	1.50	24½	12¼

NOTE: Acetylene consumption is about 3 per cent more than oxygen.

WELDING ROD

A new low-alloy, high-strength steel welding rod has been specially developed for insuring uniformly high-quality welds in high-strength pipe welded by the multi-flame gas welding process. This rod develops an average tensile strength of 10,000 to 12,000 lb. per sq. in. greater than rods previously used for pipe welding, yet has sufficient ductility to meet any requirements.

This rod is particularly suitable for use with the 4- and 6-flame tips. When applying the rod, the weld-metal sets up more rapidly, making it easier to control the puddle. This makes greater welding speed possible and also effects a reduction of gas consumption per weld.

In This View of the "One-Third Roll" Method, Two Operators Are Welding the Top Two-Thirds of the Joint

ANGLE OF BEVEL

In general, an included angle of bevel of 60 deg. is recommended for all pipe wall thicknesses. However, where accurate spacing and line-up are assured, a 50-deg. bevel can be used with a resultant increase in speed and a saving of 5 to 10 per cent in the consumption of rod and gases. On a number of jobs in the field, excellent results have been obtained by using a 50-deg. angle for heavier pipe wall thicknesses, such as 5/16 inch and 3/8 inch.

SMALL DIAMETER PIPE

For pipe diameters below 6 inches and for wall thicknesses less than 1/4 inch, the 4-flame tip should be used for rolling welds, as well as for position welds. The 6-flame tip is not recommended for rolling welds on pipe less than 6 inches in diameter because the rear preheating flames are of little value on pipe of this size.

The Operator Is Making a Bell-Hole Weld to Tie in Sections of Pipe Joined by the "One-Third Roll" Method

Table 3 lists the speeds for both rolling and position welds on pipe diameters ranging from 2 to 4 inches, using the 4-flame tip.

Table 3—Welding Speed on Small Diameter Pipe Using the Four-Flame Tip

Pipe Diameter, In.	Wall Thickness, In.	Time per Rolling Weld, Min.	Time per Position Weld, Min.
2	0.185	1	1¼
2½	0.250	1¾	2
3	0.250	2	2¼
4	0.250	2½	3

RESULTS ON HIGH-PRESSURE GAS LINE

A southwestern natural gas company operating hundreds of miles of gas lines recently installed a high-pressure, 16-inch line, using the new 4-flame tips and

high-strength welding rod. The results obtained on this line are interesting as an indication of the greater speeds possible with the new rod and tips.

The line is 20 miles in length and was completed in 27 working days. The all-bell-hole method was used on the first half of the line and a new procedure, known as the "one-third roll" method, was used on the latter half of the line.

The pipe used on this line was 16 inches in diameter, with $^1/_4$-inch wall thickness. Operators easily averaged 33 welds per 9-hr. day, with individual daily production as high as 45 welds in 9 hr. An average of 21 cu. ft. of oxygen, 21 cu. ft of acetylene and 1 lb. of high-strength steel rod was used for each weld.

Since its completion, this line has been in service carrying gas at pressures in excess of 500 lb. per sq. in. It has already gone through the coldest part of the year carrying peak loads without developing any trouble.

ONE-THIRD ROLL METHOD

Since the one-third roll method has now been adopted by this natural gas company as the standard method of pipe line construction, and has been used successfully on additional 6-, 8- and 12-inch lines, it might be of interest to describe its variations from the all-bell-hole procedure.

Briefly, the pipe joints are lined up and tack-welded on skids over the ditch in strings from 280 to 2000 ft. in length. A crew of operators first weld the top two-thirds of each joint. The weld is started at the 12 o'clock position and carried down to the 4 o'clock position on one side, then from the 12 o'clock to the 8 o'clock position on the opposite side. As soon as the string is finished, this first gang of operators moves up to the next string, keeping as close to the line-up gang as possible.

When the top two-thirds of a string is welded, the entire string is rolled one-third of a revolution. This brings the bottom unwelded third of the joint to a top position convenient for welding. The second gang of operators, half the number of the first gang, then weld up the remaining one-third of each joint in the string. This leaves one overhead weld to make on each string where it is tied into the main line.

FIELD DATA ON SIX-FLAME TIPS

Reports from the field on the 6-flame tips indicate considerably greater speeds than those formerly obtained with the 3-flame tips for rotating welding.

On one 6-inch pipe line with $^5/_{16}$-inch wall thickness and a 50-deg. angle of bevel, rolling welds were completed in $3^1/_2$ to 4 min. with the 6-flame tips. On an 8-inch line with $^5/_{16}$-inch wall thickness, the overall time per joint averaged 4 to 5 min. On still another line, operators easily averaged 40 rolling welds per 8-hr. day.

The new 6-flame tips have also proved particularly valuable for double-lengthening pipe. On one job which consisted of double-lengthening 12 miles of 10-inch diameter, $^9/_{32}$-inch wall pipe, 6-flame tips resulted in a saving of 20 per cent over methods formerly used. On another job, welding time averaged from 7 to 9 min. per joint for double-lengthening 16-inch pipe, with an estimated increase of 8 to 10 welds per man per day over that obtained with 3-flame tips.

Hoisting Engine Bed

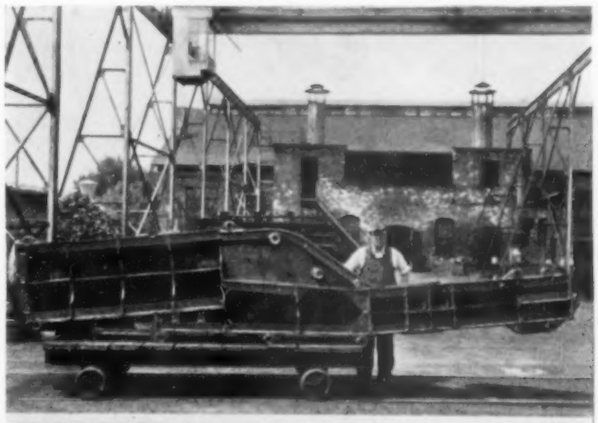
By L. O. RICHARDS*

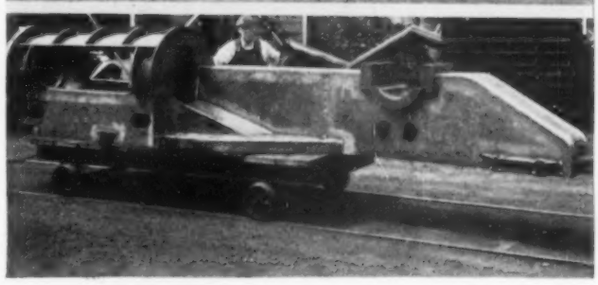
IN THE past frames of this type have always been made of a heavy cast-iron section. In severe service this usually failed at the same points due to tension which would set up in the operation. Compression stresses are found in only a couple of points. We, therefore, concluded that a frame made up of standard rolled sections properly ribbed would take the compression and tension strains and would give a better guarantee against break down in case of unavoidable wrecks or natural fatigue of the metal.

The frame in question is to be placed in operation on an engine having cylinders 28 inch in diameter by 42-inch stroke, carrying a steam pressure of around 125 lb. Hoist is brought from rest to a piston speed of approximately 600 ft. per minute in about 5 sec., the throttle remaining wide open for another 3 sec. The entire unit is again brought to rest in 6 sec. more, making a total running time of approximately 14 sec. The hoist then stands at rest for a period of from 2 to $2^1/_2$ sec., after which the cycle is again repeated. This operation takes place on an average of about 210 times an hour.

The hoist handles an up load of 22,500 lb. and a down load of 14,500 lb. in addition to accelerating and decelerating winding drum weighing approximately 40,000 lb.

No difficulty was encountered in fabrication of the frame. All plates were laid out from templates, and the frame cut to the proper sizes. Welding stresses were relieved by peening. No difficulty developed from welding strains or warping of the plates. Finished weight of the bed will be approximately 8000 lb.





Frame will be placed in operation at one of the large Peabody Coal Company mines in southern Illinois.

* Sales Engineer, Robert Holmes & Bros. Inc.

HELPING THE JOB SHOP WELDER*

By J. C. GOWING†

THIS paper is presented in the hope that it may give some assistance to the person or persons who contemplate entering the business of job welding or, we may say, a weldery, or are now operating as such. We will assume that they are just entering this venture as there are several problems which are common to the several classes of the job welding business and we will consider their separate problems later.

LOCATION

The first, naturally, is the location. Their qualifications and past experience will help to determine this. If they are familiar with the problems of an agricultural community, then the shop in a community of this kind would be most desirable. If familiar with the problems of manufacturing institutions, then establish a shop in one of the industrial centers of a large city. If one has a knowledge of the oil industry problems, then locate in or near a good oil field. Excellent opportunities will also be found in mining communities and on water fronts for marine repairs and construction.

The shop should be located as conveniently as possible to the greatest number of probable prospective customers, thus effecting economy in transportation, solicitation, and to be better able to render the customer quick and efficient service.

Careful consideration should also be given as to whether the area has sufficient prospective business to support the shop, and with ample opportunity to increase that business once started. Too many shops in a community usually cause undue competition and consequently, price cutting, which will eventually be ruinous for one or all.

The local utility company furnishing electric power should be consulted to see that the location can be or is served with ample current for the operation of arc welders and other power tools without excessive installation and stand-by charges.

A visit to the City Hall to secure information as to yearly cost of business permit and of restrictions governing their business in that particular locality is advisable.

Convenience to their source of supplies, rent and labor conditions are also matters of importance in selecting a proper location.

ESTABLISHING THE BUSINESS

Having determined the location, then come numerous details and preparation before the actual solicitation for business. If other than one individual is entering business, a competent attorney should be consulted with regard to formation of a partnership, a corporation, a company or an individual operating under a fictitious name. It is always much easier and less costly to consult the attorney before rather than after trouble arises.

Accurate records and books must be kept as our National, State, County and City governments will, from time to time, require information as regards Sales Tax, Use Tax, Social Security, Compensation, Income and other taxes. Therefore, it is advisable to have a reliable accounting firm set up books and records suitable to their individual needs.

The necessary business cards, stationery, invoice and statement forms must be printed. Equipment and supplies must be purchased.

THE EQUIPMENT

There is an old saying, "A man is known by the company he keeps." So is the job shop known by the equipment and workmen it keeps. The shop with the modern, clean, efficient equipment and good workmen, secure the larger portion of work and the best prices.

Old torches, gages and hose are wastrels of acetylene and oxygen, nor when they were new did they do as efficient work as the modern equipment of today. Arc welding, with its tremendous strides of the past few years, leaves the old generator as antiquated as the horse and buggy. If the job shop operator is considering new or additional equipment, consider carefully the modern equipment and all the advantages it has to offer and buy that equipment of ample size or capacity for their future needs, and of a type most suitable to their work.

Often there is a very definite need of economy, especially in the arc equipment where the investment is rather

* Presented at Western Regional Conference, A. W. S., Los Angeles, Calif., March 21–25, 1938.

† J. C. Gowing Company.

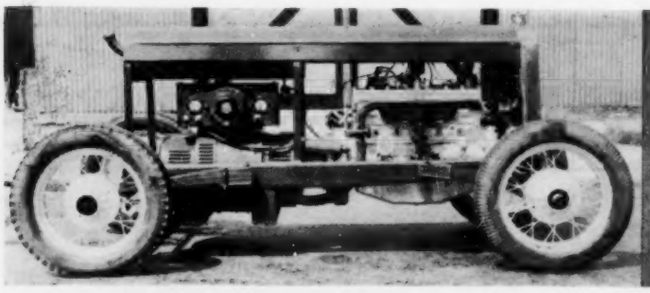


Fig. 1—A Welding Unit Mounted on Wheels

Fig. 2—Welded Horse Trailers

heavy. If used equipment is purchased, extreme care should be taken in its selection.

In the matter of the gasoline engine driven arc welder, many have purchased just the generator and constructed their own set, using either new or used engines. Many excellent sets as well as many inferior ones are being used and the cost is varied (Fig. 1).

The shop's workmen or welders have at times close contacts with the customer, especially where the work is being done in the customer's place of business. A man of pleasing personality and one who goes about his work in a thorough, workmanlike manner creates a favorable impression, and a contact from which they may expect a continuance of patronage.

SOLICITATION OF BUSINESS

Solicitation of business is usually accomplished in several manners: advertising in the local telephone directory, newspapers and trade journals, and by personal solicitation. The solicitor or owner should be well informed on welding and fabricating procedures so that he can readily analyse the customer's problems giving him approximate estimates on repairs and new construction and on prices of welded articles the shop is in a position to furnish, thus pointing out to the prospect the advantage of welding as an economical maintenance and fabricating method.

OPPORTUNITIES

Each locality presents its various opportunities, some very wide in scope and others rather highly specialized. The job shop in the small community or agricultural district requires a rather wide experience in both electric and acetylene welding. Their problem is mostly one on many small and varied jobs as their opportunities for work lie in repair on many smaller articles such as: lawn mowers, automobile repairs, fender welding, small cast-iron castings, repairing and reinforcing farm machinery, tractor repairs.

Hard-facing applications are many and varied for this type of shop, such as: pick points, plow shares, disks, cultivator points, tractor tracks and pads.

This type of work shows great profit to both customer and shop and the manufacturer of the various hard-facing metals should be consulted frequently in a search for new applications and the proper material to use on those various applications.

Many items of use to the farmer, rancher and merchant of this type of community can be fabricated by welding from standard steel shapes readily available from their supply house, such as: horse and cattle trailers, gates fabricated from new or used pipe, ornamental iron work, small and large tanks, storage bins, etc.

In connection with manufactured articles by the job shop welder, one shop, in addition to their regular work, is building horse trailers as shown in Fig. 2.

The frame is all-welded steel, using $1^1/_2$ x $1^1/_2$ x $^3/_{16}$, angle, 2 x 2 x $^3/_{16}$ angle, 3-inch channel, 3-inch I beam and 3-inch pipe.

The axle hub is from used or junk Packard automobiles and the 3-inch pipe for the axle. Plywood and lumber for the body bolted to the welded steel framework.

These trailers are very neat in appearance and sturdily built to give long service. The selling price ranges from $250 to $450 depending upon size and construction. Some are equipped with compartments for feed and harness. Air brakes are optional for an additional charge.

The shop owner states that their profit on these trailers is approximately 65% and that during the past 18 months they have built and sold over 100 of such trailers.

The oil field shop along with general repair work finds pipe welding their biggest business—rigging up for new oil or gas wells, welding field lines and boiler connections. The operators in these shops should be proficient in accurate cutting, fitting and pressure welding of pipe.

Hard-facing on oil tool bits and wearing parts on the heavy machinery also furnish a large part of the income of this type of shop.

The very necessary part of equipment for this shop is a portable welding outfit consisting usually of a gasoline engine driven arc welder, acetylene generator, torches, grinders and other tools usually mounted on a truck. In other words, a fairly complete portable welding shop. Twenty-four hour service is usually available at this shop.

The industrial shops' greatest opportunity lies in their ability to develop maintenance service to their industrial customers and to develop applications to reduce wear on machinery parts. There are literally thousands of these problems in manufacturing centers and it is a wise shop owner who studies these problems and is prepared to intelligently handle them.

A canvass should be made of the nearby manufacturing plants and the plant superintendent or maintenance man contacted. Learn the nature of his most frequent breakdowns and the parts of his equipment suffering the most wear and suggest methods of hard-facing and quick repair by welding. Many cast-iron parts fail in service and are often difficult to replace quickly. Shut downs are expensive. Many broken castings can be quickly and economically replaced by welded steel. Know your opportunities and cash in on them.

The shops in mining districts and those specializing in marine construction and repair have problems similar to those mentioned and also their specialized work so their possibilities are only as great as their ability to render a needed service to their community.

Most metals in use today are weldable with the correct materials and technique and this information can usually be obtained from the manufacturer or from the manufacturer of welding equipment or welding electrodes. There are also many good trade journals on the subject of welding which will keep the shop owner posted on late methods, materials and applications and at least one or more of these magazines should be subscribed to.

CODES

Many welding applications, repairs and manufactured articles are governed by regulatory codes and care should be taken to see that the work done and material used meets these various specifications and requirements.

COST AND RECORDS

Too much stress cannot be laid to the importance of accurate records and cost data, inasmuch as most job shops charge for their work either by the hour or by a set contract price for the completed job. The time clock with the accompanying job card will give the owner a fairly accurate cost record and description of each job. This record should consist of the following: time, labor, welding wire, material, power cost, acetylene and oxygen and overhead.

The cost of the labor is definitely fixed at a price per hour. The welding wire is the same, as this amounts to the pounds consumed at a certain price. Other material such as steel going into the job has a fixed cost. The power cost is more or less approximate. However, the manufacturers of arc-welding equipment will furnish the approximate cost of power consumed for the various size welding rods at their average welding heat. Likewise, the manufacturers of torches and the suppliers of acetylene and oxygen will furnish charts and information as to the approximate consumption for the various tip sizes.

Overhead is usually charged as a percentage of the known fixed cost of the job, and is that cost of operating the business which must be pro-rated among all of the jobs done over a period of time as monthly or yearly. The total overhead of a shop consists of such charges as the following: rent, telephone and telegraph, advertising, insurance, interest, heat, light, depreciation of equipment, postage, printing and stationery, taxes, automotive upkeep, fluxes and other supplementary materials not chargeable to any particular job; and unproductive labor such as stenography, bookkeeping, solicitor's and foreman's wages or salary.

This overhead cost per month should be known to a reasonable degree of accuracy and knowing the total fixed cost of all jobs done in the same period of time, the percentage of overhead can be calculated. Then adding a reasonable percentage for profit, you have a fairly true picture of each job and a record that will materially assist in estimating future work.

Let us look for a moment at a recent job brought to a shop for welding. It is a small pressure vessel used in conjunction with a piece of equipment manufactured for the dry cleaning industry. All material to be welded was furnished by the manufacturer.

The vessel is 18 inches in diameter and 40 inches long, and of $^3/_{16}$-inch plate. The manufacturer had purchased the shell with the longitudinal seam already welded. The bottom of $^1/_4$-inch material was dished and to be welded 2 inches from the bottom of the shell with $^1/_4$ fillet weld, a ring 1 inch x 1 inch to be welded flush to the top of the shell on the outside, the weld to be on the bottom of this ring only and to be a $^3/_8$-inch fillet; four cast-steel clamp connections to be welded to the side of the shell with $^1/_4$-inch fillet, 10 inches of welding on each; four clamp connections to be welded to the head with $^1/_4$-inch fillets, 7 inches of welding on each; one 6-inch clean-out outlet of cast steel to be welded near bottom of shell with $^1/_4$-inch fillet, two $^3/_4$-inch connections, one $^1/_4$-inch connection, and two $1^1/_2$-inch connections to be welded into the shell.

Having several of these to weld, the first operation was to lay out and cut the holes in the shell for connections. The cutting time amounted to 5 minutes each. His manufacturer's chart told him that with a No. 1 cutting tip his oxygen and acetylene cost was five cents.

His time for laying out, cutting, tacking in of connections, head and ring amounted to an average of one hour per unit.

His final operation was welding and with the exception of the smaller connections $^3/_{16}$-inch heavy coated electrodes were used. His time he found to average one hour and five minutes each. He consumed 6 pounds of welding rod at twelve cents per pound.

The electric current consumed was his average welding current, 200 amperes at 25 volts at the arc, or 5 kw. Figuring the machine at welding time and idle time as 50% efficient, gave him 10 kw. This current cost was three cents per kilowatt hour or thirty cents per hour for current consumed.

His overhead being approximately $33^1/_3$%, he now has the following picture of the job:

Labor at 2 hours, 5 minutes at $1.00 per hour	2.08^1/_2$
Oxygen and acetylene	.05
6 pounds welding rod at 12¢	.72
Electric power, 1 hour, 5 minutes	.32$^1/_2$
Total	$3.18
Overhead	1.06
Actual cost	$4.24

He could easily have estimated the cost of his actual welding operation by consulting one of the welding equipment or electrode manufacturer's charts compiled for the purpose. In fact, one chart the writer consulted, states that the cost of $^1/_4$-inch fillet in the down-hand position costs nine cents per foot and $^3/_8$-inch fillet in the down-hand costs 19 cents per foot. Considering the above problem, he has 159 inches of $^1/_4$-inch fillet and 56 inches of $^3/_8$-inch fillet, or for ease of calculating 13 feet of $^1/_4$-inch fillet and 5 feet of $^3/_8$-inch fillet, or a cost of $2.12 which includes labor at $1.00 per hour, rod cost and power consumed. It does not, however, consider overhead. The above cost for the actual welding was $2.13.

This would tend to show the value of these charts in the estimating of welding costs.

Shops that charge by the hour should look very carefully into their various costs, and if a flat rate per hour is charged, the rate should be only for the operator and equipment and a separate charge in case of the arc welder for welding rod cost as the rod cost on stainless steels, hard-facing applications, and alloy steel would be much higher than mild steel applications. In the case of the acetylene welder, the acetylene and oxygen consumption would vary greatly with the type of work and size of tip used.

In the case of portable work away from the shop, a reasonable mileage charge to the customer's place of business and return should be made.

In conclusion, I might say Welding is in its infancy. It will continue to grow, its opportunities increase and the job shop owner who will grow and prosper is the man who will keep apace with this growing industry and its developments, and efficiently render a needed service to his community.

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LEAD WELDING, OR "BURNING"

By F. E. ROGERS†

LEAD, a bluish-white metal, very soft, pliable and ductile in the commercially pure state is widely used for linings in vats and tanks, and for containers and pipes carrying corrosive and semi-corrosive liquids, especially in chemical plants. Lead sheets are used also for covering the wooden frames of machines, tables, stands and floors in such plants where cast iron or other metals and materials exposed would quickly be disintegrated by the acids and alkalies employed in the processes.

Lead in sheets and pipe is used also for water lines, tanks, swimming pools, X-ray room linings, protectors under shower rooms, toilets, urinals and bathrooms; for roofing valleys, gutters, leaders, flashings, cornices, sheathings on metal pipes and electric cables and for many other purposes above and below ground because of resistance to air, water and soil corrosion.

IMPERMEABLE JOINTS REQUIRED

For most if not all the foregoing uses and others not so far named, it is necessary that the seams or joints be made impermeable to liquids. The jointures must be water- or acid-tight at the outset, and they should remain so indefinitely which indicates that the joint metal, therefore, should have substantially the same corrosion resistance and tensile strength as the base or parent metal. The requirement means, as a rule, that the seams must be autogenously welded, that is, fused together using a lead filler metal of substantially the same analysis as the base metal. The process required for jointing acid containers is essentially different from "lead wiping," both in the method of forming the joint and in the make-up of the filler metal. Wiped joints are made with an alloy of lead and tin, or solder, commonly 60 per cent lead and 40 per cent tin which melts at about 400° F., whereas an autogenously welded joint will be all lead, melting at about 621° F.

LEAD "BURNING"

Lead burning so-called is the welding of lead with a gas torch or blowpipe, using a combustible gas and compressed air, or oxygen. The edges of lead sheets are butted or lapped. They are fused and flowed together, using no solder but only "chemical" or commercially-pure lead to fill and reinforce when and if a filler metal is required. The term lead "burning" therefore is a misnomer as the lead is not burned but instead is fusion welded with the torch, as are other metals. The methods employed in lead welding practice differ quite widely from those used for other gas welding applications, however.

ORIGIN OF LEAD WELDING

Technique of making up the joints in lead pipe plumbing found buried under Roman ruins more than 2000 years old is not fully known. Some claim that the joints were made by pouring molten lead upon the pipe while cased or molded in sand, the operation being essentially the same as "burning-on" missing gray iron casting parts, an operation sometimes made in iron foundries before the advent of oxyacetylene welding. They may also have been soldered with a lead-tin alloy melting at a lower temperature than lead.

The origin of lead welding with the gas torch as now known dates back little more than one hundred years. In 1837 a French engineer, Monsieur de Richemont, invented or developed the first air-hydrogen torch using compressed air from a hand or foot bellows and hydrogen generated from zinc and sulphuric acid for the autogenous welding of lead sheets and lead pipe. Hence, lead welding as a separate and distinct process for jointing lead as distinguished from lead casting or "burning-on," and soldering or "wiping" is considered as having originated about 1837.

USES FOR LEAD WELDING

The lead welding process is employed in applying lead sheet linings ranging from $^1/_8$ inch to one inch or more in thickness to sulphuric acid and other tanks in chemical plants, fertilizer factories, rubber reclaiming works, electroplating shops, artificial silk or rayon factories, nitroglycerine huts and industrial plants in general that employ corrosive liquids requiring impermeable lead-lined tanks and pipe lines.

In other special fields, such as storage battery manufacture and repair, lead welding has become of increasing importance. Widespread and well-nigh universal use of storage batteries for railway passenger car lighting and automotive car and truck lighting and engine starting have created demand for lead welding equipment, gases and supplies in storage battery manufacturing plants, garages and battery service stations. These places employ lead welding in making up the lead plate or grid connections and terminals. There is, however, a wide difference between the practices of lead lining tanks for chemical plants and making up storage battery parts. The following notes pertain chiefly to lead welding of sheet and pipe used in storing and carrying corrosive chemicals.

CHEMICAL LEAD

Lining and pipes for acid tanks and lines are made from so-called "chemical" lead as distinguished from other lead. Chemical lead does not differ greatly in purity from the purest commercial lead as will be apparent from an inspection of the compositions of standard grades of lead, Table 1. In this Table are compared chemical, purest commercial and common leads. Lead from the mines of southeastern Missouri, containing small quantities of silver, copper and nickel being preferred for chemical tank lining service, has received the designation of "chemical" by common consent not because of superior

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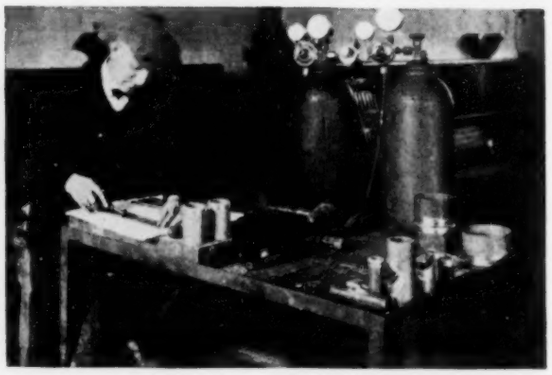

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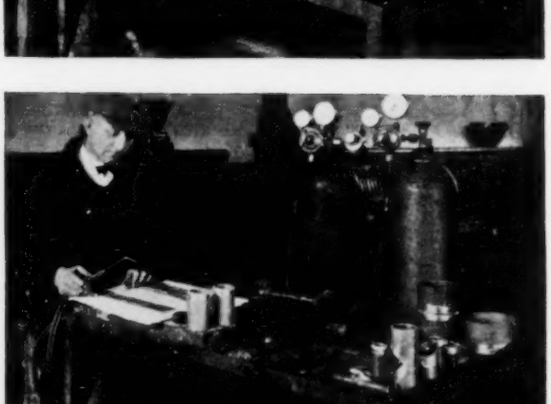

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Fig. 1—Tools Used in Lead Welding, Comprising Handsaw, Mallets, Pliers, Scrapers, Chisel, Rasp, Snips, Cutter, Burnisher and Welding Rods

Fig. 2—Operator Scraping a Joint in 8-Pound Sheet Lead to Prepare It for Welding. All Oxide Must Be Removed

Fig. 3—Samples Prepared for Welding

Fig. 4—Making Reinforced Ripple Butt Weld, Level Seam, in 16-Pound Lead, Oxy-Calorene Flame

purity but for its general adaptability to chemical use, including, of course, weldability.

Table 1—Composition of Standard Grades of Lead

	Chemical	Purest Commercial	Common	Corroding for White Lead
Silver (Ag)	0.0068	0.00055	0.0005	0.0005
Copper (Cu)	0.062	0.0003	0.0003	0.0003
Arsenic (As)	None	Trace	Trace	Trace
Tin (Sn)	None	None	Trace	Trace
Antimony (Sb)	0.001	0.0012	0.001	0.001
Bismuth (Bi)	Trace	Trace	0.089	0.0045
Cadmium (Cd)	0.0008	0.0006	0.0003	Trace
Zinc (Zn)	0.0002	0.00024	0.0001	0.0002
Iron (Fe)	0.0002	0.0003	0.0004	0.0002
Nickel (Ni) and Cobalt (Co)	0.0048	Trace	0.0004	0.0002
Manganese (Mn)	Trace	Trace	Trace	Trace
Lead (by diff.)	99.924	99.9968	99.9090	99.9528

Table 2—Physical Properties of Lead

Atomic weight	207.22
Atomic volume	18.27
Density 20° C. (68° F.) cast	11.34
327.4° C. (621.3° F.) solid	11.005
327.4° C. (621.3° F.) liquid	10.686
550° C. (1022° F.) liquid	10.418
Melting point, 327.4° C.	621.3 F
Boiling point, 1525–1620° C.	2777–2948 F.
Thermal conductivity 0°C (32° F.)	0.083
Coefficient linear expansion, 17–100° C. per degree C.	0.0000293
Coefficient linear expansion, 62.6–212° F. per degree F.	0.0000163
Brinell hardness	3.2 to 6.0
Elastic limit, lb. per square inch	284
Tensile strength, lb. per square inch	1900
Modulus elasticity in tension	800,000–2,000,000

ANTIMONY LEAD

Because of high specific weight, low-tensile strength and pliability sheet lead linings of deep tanks are likely to "crawl," buckle or tear if supported at the top only, or if not reinforced. To meet such conditions in the chemical industry, lead, containing, say, six to twelve per cent antimony, is used, or chemical lead in the thicker sections strengthened by antimonial lead bars running the full length of the sheets. This reinforcement is not unlike the principle, the steel reinforcing bars in concrete.

Lead containing six per cent antimony has nearly twice the tensile strength of chemical lead and ten times the elastic limit. The alloy is lighter than chemical lead also which fact favors its use where greater strength than that of chemical lead is required. Thus, the weight of six per cent antimonial lead is 95 per cent of chemical lead while the weight of lead containing ten per cent antimony is about 92 per cent of equivalent chemical lead.

Antimony lead is used with exceptionally good results for self-supporting ducts, vats and especially on rayon spinning machines where a backing of other metals or materials is not necessary to hold it in shape. Such backings are necessary if soft or chemical lead is used.

Although resistance to corrosion of antimony lead is somewhat less than that of chemical lead, it is sometimes better to sacrifice four to eight per cent corrosion resistance, and gain the heat-resisting qualities of this lead.

Table 3—Chemical, Six Per Cent and Twelve Per Cent Antimony Lead

	Chemical Lead	6% Antimonial Lead	12% Antimonial Lead
Melting point or range	620° F.	477–545° F.	477° F.
Specific gravity	11.36	10.88	10.45
Weight per cu. ft.	710 lb.	677 lb.	654 lb.
Weight per cu. in.	0.41 lb.	0.392 lb.	0.377 lb.
Tensile strength in psi			
Rolled	2300	4100	
Extruded		3300	3800
Cast		6700	7300
Coefficient of linear expansion per degree F.	0.000016	0.000015	0.0000145

TELLURIUM LEAD

Tellurium lead which was developed in Great Britain a few years ago and which is being used quite extensively in the United States because of superior tensile strength, fine grain size and chemical resistance is virtually pure lead containing less than one per cent tellurium.

Tellurium sheet lead can be bent double and hammered without fracture which fact coupled with excellent weldability makes its application to large acid chambers advantageous, especially where subjected to vibration. Welding procedure is essentially the same as with chemical lead except that filler or "burning bars" should, of course, be made of tellurium lead in order to assure a homogeneous joint structure.

This lead alloy is particularly valuable for situations requiring heat resistance as well as corrosion resistance, that is, for example, where chemical reactions and steam coils develop temperatures up to 200 to 220 degrees, or higher.

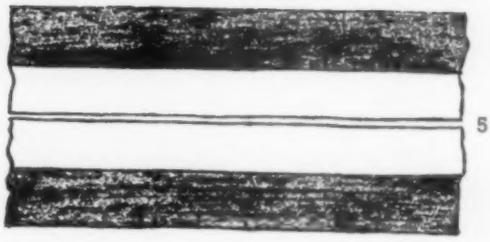
CONDITIONS AND EQUIPMENT FOR WELDING

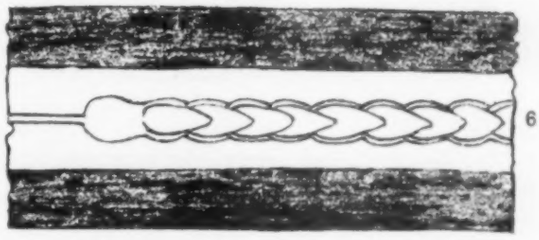
Considerable special skill is required of a lead welder to unite lead sheets rapidly and uniformly in all positions, that is, downhand or flat, horizontal, vertical and overhead. The beginner is likely to overheat and fuse or "burn" holes through the joint, to say nothing of his difficulties in making welds rapidly that measure up to the exacting standards of lead joint work. The trade of lead welding may be learned, however, in a reasonable period by an intelligent workman provided he has competent instruction and suitable equipment. Success depends on good tools, thorough preparation, clean surfaces, suitable torch equipment, combustible gas used, chemical lead and proper working conditions as well as the skill of the operator.

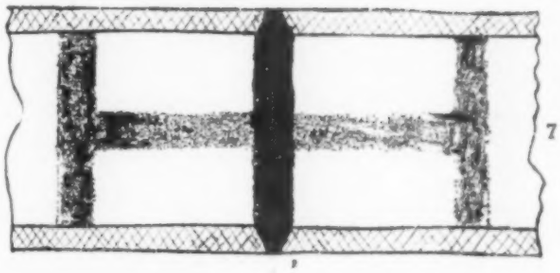
BUTT AND LAP JOINTS

Two forms of joints are used with sheet lead—the butt and simple lap seam. Both are employed in lining tanks and vats, and also in welding lead pipe. A butt joint is that made by placing two sheets edge to edge while a lap joint is one in which the sheets are overlapped one above the other. A butt joint may be either with square or bevel edges, depending on the weight of the sheet.

In preparing a butt joint for the heavier weights of lead where filler metal is used, the edges should be trimmed straight and then beveled to an angle of 75 to 80 degrees. Two edges thus beveled make a vee having an included angle of 25 to 30 degrees when set opposite for welding.







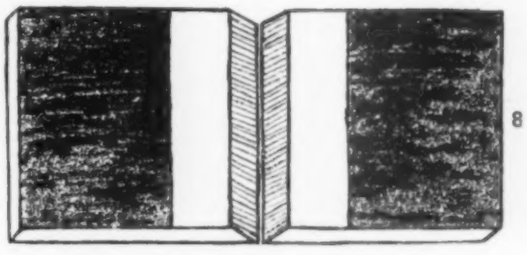


Fig. 5—Lead Sheets, Edges Scraped for Butt Weld

Fig. 6—Butt Reinforced Weld in 4-Pound Sheet Lead, Ripple Space 7/16 Inch

Fig. 7—Split Joint in 2-Inch Inside Diameter Extra Strong Lead Pipe. Bottom Welded from Inside of Pipe. Light Lines Show Split Welds

Fig. 8—Beveled 30-Pound Lead Sheets Ready for Welding

The upper and lower sides of both sheets are scraped clean and bright to remove all lead oxide back at least one-half inch from the edges, using a sharp "shave-hook." The edges are placed close, and tacked, placing the tacks about one foot apart on heavy lead, and the groove or vee between is filled with molten lead fused with the torch from the end of a welding rod or 'burning-bar."

The welded seam usually is reinforced with lead which when applied in the downhand position flows and forms peculiar overlapping patterns, varying in spacing and width with the weight of the lead sheet and size of the burning-bar. The spacing and to some degree the pattern are controlled, of course, by the welder in fusing and dropping the molten lead on the joint.

Butt joints are not much used in tank and vat linings, however, except the linings be made with very heavy

Fig. 9—Butt Welding 4-Inch Lead Pipe Oxy-Calorene Flame

Fig. 10—Lead Welding Bottom to Acid Pot, Oxy-Calorene Flame

Fig. 11—Making a Vertical Lap Weld, Using no Filler Rod, 6-Pound Sheet Lead

Fig. 12—Samples Oxy-Calorene Flame Welded Lead Joints and Prepared Pieces

lead, so thick in fact that it is rarely used. In some chemical industries the larger investment required is accepted, however, because of the longer life and reduced interference with process flow.

When making butt joints all thicknesses up to, say, 12 pounds per square foot ($^3/_{16}$-inch thick) are butted with square edges, and are generally welded with filler or welding rod. Edges of sheet lead heavier than 12 pounds per square foot are beveled as previously described to form a vee groove of about 25 to 30 degrees included angle. Whether square or bevel preparation, the lead oxide must be thoroughly removed from both sides close to the joint. The reason for removing the oxide from the far side is the presence of oxide at the edges interferes with the flow or penetration of the molten lead through the joint, whereas if clean a slight reinforcement will be a result.

HOW BUTT JOINTS ARE WELDED

When welding a lead butt joint with filler from a burning-bar the flame envelope or streamer is played on the edges of the sheets until the metal is softened but is still too stiff to flow freely. Lead is added from the filler rod by fusing from the end, also with the flame envelope, giving the torch and filler rod a periodic up-and-down and forward movement which deposits the required amount of molten lead at each forward step.

The deposited lead flows down between the beveled edges and fuses them together with the bond, and forms a reinforcing pattern on top. The shape and thickness vary with the thickness of lead, weight of the filler rod, size of flame and amount of lead deposited at each movement. The next application of lead fused from the filler rod, if accurately spaced, flows into and overlaps that just previously laid down. The lead welder progresses in the manner described, laying down drops or rather "globs" of molten lead evenly spaced along the joint, thus making an attractive chain pattern.

HOW LAP JOINTS ARE WELDED

Lap seams are mostly used in tank linings, especially in the vertical joints when a smooth surface is not required. In making up a lap seam, the upper sheet should lap over the under sheet one to one-and-half inches. The lapping surfaces and upper edge—three surfaces in all—must be made scrupulously clean by scraping all oxide off with the shave-hook or a hook scraper. When cleaned, they must not be soiled with the hands or by touching other objects.

When making a lap lead weld, especially in a vertical joint, the torch flame is directed close to the edge of the upper sheet. No burning bar or filter metal is used. Manipulation of the torch flame is quite different from that employed when making flat or downhand welds of either the butt or lap type. Not much lead can be melted at a time because of the difficulty of control and probability of running off and dropping. The overlapping edge is "carved" with the flame, that is a lunar shape is cut out or fused and the molten metal slides or slips down upon that previously carved out where it coalesces and hardens.

The lead welder sometimes uses a tool—a shave-hook for example—to hold the lead sheets closely together, and also to accelerate chilling the fused lead should it tend to slip down too far, or drop off entirely.

The fusion welding process on vertical lap seams, the same as on flat butt seams on which filler metal is applied, is a succession of in-and-out and progressive torch

movements with each application of the flame, but the flame is also moved sideways about one-fourth inch, thus "carving" out a section of the upper sheet edge which fuses, flows down and comes to rest upon the previous deposit.

WELDING EQUIPMENT AND GASES

Temperature required for fusing lead for welding is low in comparison with that required in welding cast iron, or steel, being of the order 610 to 625° F., as compared with 2000 to 2700 degrees for cast iron and steel. Hence, hydrogen or city gas are as a rule used in preference to acetylene on the lighter weights of sheet lead. If high temperature acetylene is employed, it means smaller tips than when using hydrogen.

Small light torches are used that can be easily handled. Old-time lead burners were trained to use hydrogen (generated with acid and zinc) and compressed air, but the introduction of oxy-gas welding equipment and compressed oxygen, hydrogen and acetylene in convenient cylinders has changed lead welding practice to a considerable degree. However, very simple and cheap torches are employed as a rule with hydrogen, consisting of little more than a light tube bent to a gooseneck and fitted with separable tips. The mixed gases are supplied by means of a light rubber tube connected to a bench-block which carries the adjusting needle valves. This arrangement enables the operator to adjust the valves to the flame he desires, and then he can go ahead with his work without danger that the flame may be changed by accidentally touching the valves as might happen if the valves were on the torch. With the primitive torch just described, in the case of a flashback about all that happens is the rubber tube is blown off the bench-block as it is not wired to the gland.

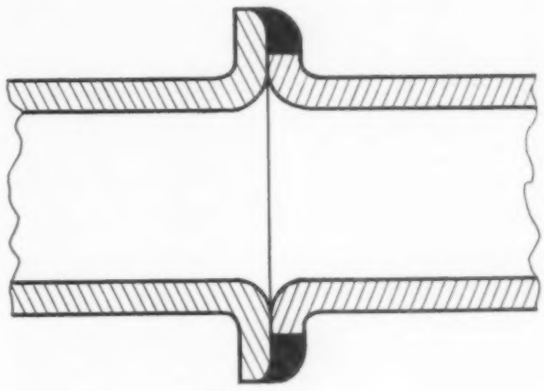
The lead welder necessarily becomes expert in working lead within narrow temperature limits. He must heat the metal at the joint to the near fusing point but not so much that it becomes too fluid and drops away. He must scrupulously clean the joints and avoid touching them with the hands or anything unclean, as the slightest trace of oil or grease will give trouble. The first operation to be learned is to choose the tip size and regulate the flame. The volume of heat necessary will depend upon the thickness of lead being burned and to some extent on the surrounding conditions and the backing.

WEIGHT OF LEAD, AND SIZES OF BURNING BARS

Lead sheets, 2, 4, 6, 8, 10, 12, 16, 20, 24, 30, 40 and even 60 pounds to the square foot are used in chemical plants. Thus, twelve thicknesses of lead, ranging from 2 pounds to the square foot to 60 pounds to the square foot, the latter being thirty times as thick as the former, are presented for welding. Hence, it is quite apparent that the lead welder must be able to regulate and adjust his flame to a wide variation in the thickness and weight of lead.

A lead welder of long experience is shown using a torch with a tip, No. 68 drill size (0.031 inch) consuming about 2.6 cubic feet of acetylene per hour. The same tip will burn 10 cubic feet of hydrogen per hour at the same pressure He would use this tip on 2-, 4-, 6- and 8-pound lead. A No. 62 drill size tip (0.0380), with hydrogen, should be used with 10-, 12-, 16- and 20-pound lead. An oxyacetylene torch with a neutral flame may be used with tips on heavy lead ranging from 24 pounds to 60 pounds, consuming 2, 5 and 8 cubic feet of acetylene per hour.

Fig. 13—Flange Weld in $1^1/_2$-Inside Diameter Extra Strong Lead Pipe



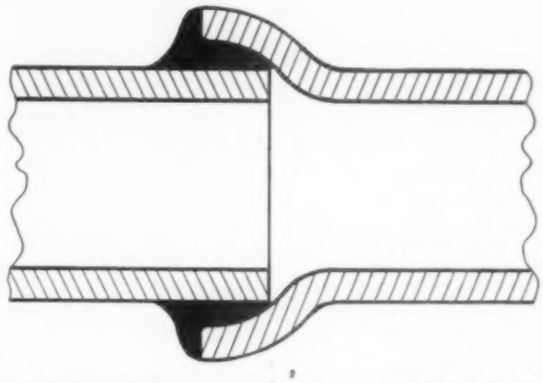


Fig. 14—Welded Cup Joint in $1^1/_2$-Inch Inside Diameter Extra Strong Lead Pipe

WELDING RODS OR "BURNING BARS"

The cross section of the lead filler or "burning bars" depends on the thickness or weight of lead to be welded; $^1/_8$-inch wire size is recommended for 2-pound and 3-pound lead; $^1/_4$ inch for $3^1/_2$-pound and 5-pound lead, $^5/_{16}$-inch size for 6-pound and 8-pound lead; and $^3/_8$ inch and $^1/_2$ inch, depending on the type of seams, for 10-, 12-, 16- and 20-pound lead.

The importance of using lead welding rods of the correct size for each weight of lead can hardly be over emphasized. If the bar is too light, the time required to fuse the lead needed for each deposit permits oxidation to take place due to the fact that the metal is light and is likely to be overheated. If a heavy bar is used with a small flame, the metal does not melt sufficiently to carry on the seam, and the seam chills during the lost time period while the flame is melting the lead. Fusing the filler is done over the sheet of course, and the time interval between fusing the burning bar and depositing it on the sheet must be carefully gaged. If the bar is too heavy or too light, the proper sequence of heating the sheet, fusing the lead, depositing it on the seam and so on, cannot be maintained as to time interval. This means lost time, irregular work, low speed and oxidation, edges of seams not welded, pits, cold-shuts and other defects.

A well-regulated flame of size in proportion to the weight of lead and the proper size of burning bar are important also on pipe work, the same as on sheet lead.

As previously stated, great care must be taken in properly scraping all dirt and oxide from the surface with

the shave-hook before burning. Avoid rubbing the hands over the work after scraping. Always use a dust brush or counter brush to remove the scrapings or raspings produced in preparing a joint.

After the lead is scraped clean at the joint, brush the shavings away from the seams and from beneath. Dress the lead down tight to the tank with a wooden mallet, tack the edges together with the torch at, say, every foot, but always keep the lead dressed down flat to the tank surface. This saves time in welding and prevents molten lead getting beneath the sheet.

LINING TANKS

Should the welder be relining an old box or tank where the wood has been saturated with the contained liquors, use a strip of sheet asbestos about three inches wide under the seams. The bottom of the tank should be wiped dry and made as free from moisture as possible. The asbestos insures against the acid or liquor soaked into the wood from bubbling up through the seams when the burning is being done. Watch carefully back of the flame to see the bubbles do not break through. Gas will often do this between the tank and lining, and of course if this happens a defective spot is formed which must be made tight.

Table 4—Weights and Dimensions of Lead Sheets. National Lead Company

Weight Lb. per Sq. Ft.	Thickness Sheet Inches	Size Sheet Feet*	Tip Drill Sizes†	Welding Rod Diam.‡ Inches
1	1/64	8 × 20	#72 (0.0250)	..
1 1/2	1/48	8 × 20	#72 (0.0250)	..
2	1/32	7 × 45	#68 (0.0310)	1/8
2 1/2	1/24	9 × 45	#68 (0.0310)	1/8
3	3/64	10 × 45	#68 (0.0310)	1/8
3 1/2	1/17	10 × 45	#68 (0.0310)	1/4
4	1/16	10 × 45	#68 (0.0310)	1/4
5	5/64	10 × 43	#68 (0.0310)	1/4
6	3/32	11.5 × 30	#68 (0.0310)	5/16
8	1/8	10 × 40	#68 (0.0310)	5/16
10	5/32	11.5 × 40	#68 (0.0310)	3/8
12	3/16	11 × 40	#68 (0.0310)	3/8
14	4/17	11.5 × 40	#68 (0.0310)	1/2
16	1/4	11.5 × 40	#68 (0.0310)	1/2
20	5/16	11.5 × 40	#68 (0.0310)	1/2
24	3/8	11 × 34	#62 (0.0380)	5/8
30	1/2	11 × 27	#62 (0.0380)	5/8
40	5/8	11 × 24	#62 (0.0380)	5/8
60	1	12 × 12	#56 (0.0465)	5/8

* Other sizes of sheets than those listed are available in certain weights.

† Tip drill sizes are for hydrogen up to 20-pound lead, inclusive, and for acetylene, 24-pound lead up. Oxyhydrogen is used for the heaviest lead also, however.

‡ No welding rod or "burning bar" size is specified for 1-pound and 1 1/2-pound lead. Light lead is generally welded with flanged or standing seams, using no welding rod.

Again, where iron tanks are lead-lined, care must be taken that gases are not formed between the tank and lining. But as this work is in a class by itself the matter will not be further treated here except to say that gas formed back of linings is one of the major troubles that the lead welder must guard against.

Upright or vertical seams must be scraped, as follows: Lap the lead 1 inch to 1 1/2 inch, scrape the lower or back sheet before the lead is dressed down. Do not fail to scrape the under side as well as the outside. This is why some lead welders have much trouble in upright or overhead welding. Everything depends in this class of work on properly-prepared joints and proper regulation of flame. Remember also that a drop of metal lost on overhead work must be replaced with one from the welding rod or burning bar, otherwise the seam will look bad, and it will be hard to start back at the edge of the sheet. Overhead welding requires practice and care to prevent the flame from distributing heat except where the burning is actually being done.

Table 5—Lead Pipe Sizes Used in Chemical Plants

Inside Diameter Inches	Outside Diameter Inches	Weight per Foot Pounds	Weight per Foot Ounces	Thickness of Wall Inches
1/4	11/32	0	4	1/16
1/4	7/16	0	8	3/32
3/8	23/32	1	9	11/64
1/2	11/16	2	1	5/32
3/4	15/32	3	0	13/64
1	17/16	4	0	7/32
1 1/4	1 43/64	4	12	7/32
1 1/2	2	6	8	1/4
2	2 1/2	9	0	1/4
3	3 1/2	12	8	1/4
4	4 1/2	16	12	1/4
6	6 11/16	24	0	5/16

Other and larger sizes of lead pipe are available also for special conditions

LEAD PIPE WELDING

Lead welding is used exclusively for all kinds of lead work joints in chemical plants. Wiped or soldered joints are seldom or never satisfactory. Flanges are used only where lines are to be broken from time to time, due to various causes, such as clogging with sediment or being eaten up by acid or residues and where time is an important factor requiring quick repairs. Even then only a few flange joints are generally permitted. Most joints are welded, making a 100 per cent job, and eliminating leaks almost inseparable from flange joints.

Washout openings are placed in certain lead pipe lines so that they may be cleaned quickly. When such a line is a vital part of the operation, all joints should be carefully welded so that the joints will withstand more corrosion than the pipe itself, or, in other words, the welding does not pit the wall of the pipe or take any lead from the wall thickness. In making such pipe joints, always add from the welding rod or burning bar to build up the seam or joint.

The following lead pipe joints are recognized and used in lead pipe work: Roll, cup, butt, split, flange, burned-in, flange using cast-iron or brass flanges, and lap. See sketches and table of sizes and weights of lead pipe.

WELDING LEAD BUTT JOINTS WHEN THE UNDERSIDE IS INACCESSIBLE

Often the maze of lead pipes in a chemical plant includes some so laid that the underside is inaccessible for welding. When it becomes necessary to replace a section and weld it in with butt joints heavy expense would be incurred for removing and replacing the underneath obstruction, or cutting several side connections and re-welding.

In such cases the pipe ends are split back at the top two or three inches. Cross cuts are made at the ends of the splits about halfway through, or down to the middle of the pipe, as shown in Fig. 7. The split parts

of the pipe are bent outward, thus exposing the inside and permitting the underside of the butt weld to be made by working on the inside of the pipe. When the weld is made halfway around the cut parts are bent back into place and the cross cuts, splits and butt welds are made, thus closing the pipe and completing the job.

If the ends of the pipe are beveled, the lower halves are beveled inwardly, and the upper halves as usual.

Acknowledgment of information and data furnished is due to Mr. W. H. Carter of Carter Metal Fabricating Co., Buffalo, Mr. G. O. Hiers, National Lead Company, Brooklyn, New York and Mr. O. G. Kelley of O. G. Kelley & Company, Boston, Mass.

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Longest String of Welded Well Casing Is Set in Oklahoma

By A. F. DAVIS†

THE longest string of welded casing used to date was set recently by the Carter Oil Company in their Carter-Harley No. 1 well near Milroy in Carter County, Oklahoma. The length of the string was 8100 feet.

The National Tube Company's 7 inch O.D., 26-pound, range 3, special casing was used. Two types of joints were welded, the "U" bevel on plain end pipe and the "V" bevel, commonly used on shorter strings.

† Vice-President, Lincoln Electric Co.

L. R. Hodell of the Carter Oil Company supervised the job, with Boris Robinoff and H. M. Cooley of the National Tube Company and R. L. Looney, Welding Engineer for the Big Three Welding Equipment Company and Lincoln Electric Company, also on the derrick floor.

The job was completed successfully without encountering any difficulties. In testing after the casing was set, pump pressure was built up to 1200 pounds and allowed to stand for 45 minutes, at the close of which period the pressure had not diminished, indicating beyond all doubt that the work was a success.

R. W. Kirkpatrick, Division Superintendent, with Glen Howard, Welding Foreman of the Carter Oil Company and R. L. Looney, closely inspected the work to make sure that all welds had 100 per cent penetration and a neat appearance.

The success of this job opens a broad field for welded well casing joints throughout the United States.

Fig. 1—Arc Welding 8100-Foot Well Casing, Longest Welded String on Record

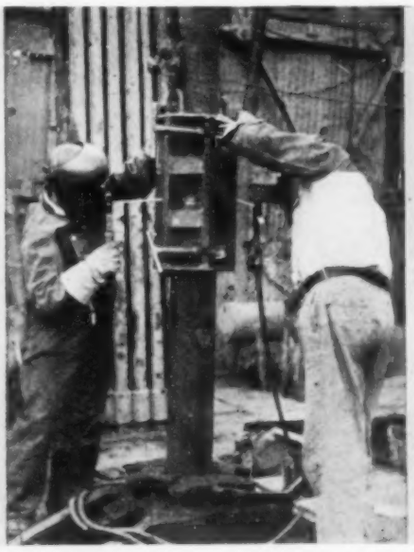


Fig. 2—Close-Up Showing Line-Up Clamp Holding Casing Pipe in Position for Welding the Joint

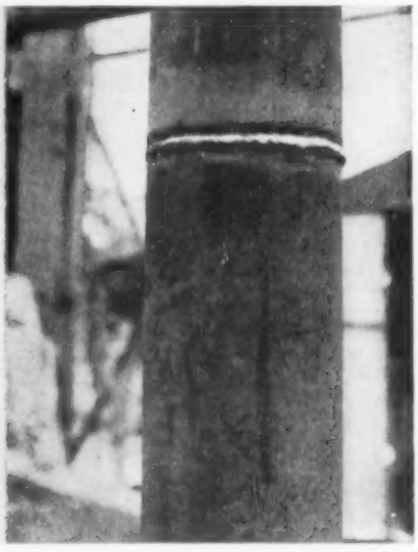


Fig. 3—Finished Weld Connecting Pipe on World's Longest Welded Well Casing

NEW LIFE FOR OLD RAILROAD Bridges*

Thirty-Year-Old Steel Spans Strengthened to Take E-60 Loading

By GEORGE G. THOMAS†

LAST year (1937), when the Atlantic Coast Line Railroad purchased a number of 4–8–4 type locomotives with 65,000-lb. driving-axle loads, it became necessary to strengthen several small steel bridges that had been in service for thirty years or more. Orginally designed for Cooper's E-40 live load, they would have been seriously overstressed under the new conditions.

The structures involved include one double-track through-truss span (102 ft. in length between end bearings) and 37 single-track deck-girder spans varying from 30 to 74 ft. in length and aggregating 1575 linear ft. They are all located on the main line, between Richmond, Va., and Jacksonville, Fla., and between Waycross and Albany, Ga.

Previous experience of the Metal Bridge Department clearly indicated that a combination of electric welding and riveting would be the most practical and economical method to follow in applying the reinforcement. The program as adopted has required a labor force consisting of a foreman, 16 men and a cook. Four men are kept in the bridge yard fabricating the steel, while the remainder comprise the field crew. The field equipment includes two 300-amp. direct-current electric welders and one 160-cu. ft. air compressor.

Preliminary engineering for the program consists of (1) field inspection of each span; (2) mathematical analysis of the stresses in each span; and (3) determination of the reinforcement needed in main sections or details. Complete detail drawings are prepared for use of the bridge yard force in fabricating the reinforcement, and the same drawings are then used as a guide for the proper application of the new material. The analysis of stresses is made in accordance with the Rules for Rating Existing Iron and Steel Bridges, 1936, of the American Railway Engineering Association. These rules are supplemented by the Specifications of the AMERICAN WELDING SOCIETY, 1936, for the Design, Construction, Alteration and Repair of Highway and Railway Bridges by Fusion Welding.

A detailed description of the work at two bridges will suffice to illustrate the methods employed at all sites. For our first example, let us consider the 30-ft. deck-girder span shown (with the new reinforcing) in Fig. 1.

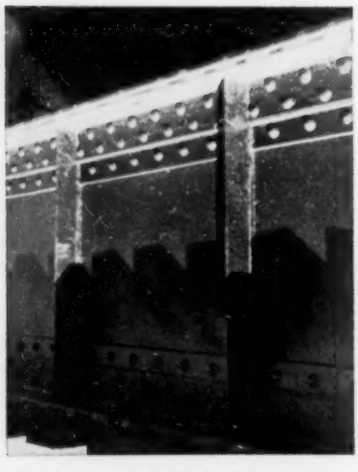
Like all the others, this bridge had been designed for Cooper's E-40 live load. The computed stresses for the new locomotives showed the following parts of the span to be deficient:

1. Flange area, owing to original design and to rusting and mechanical wear during 33 years of service.
2. Strength of rivets connecting flange angles to web.
3. Bearing area of end stiffener angles.
4. Top laterals and cross frames.

In the lower right corner of Fig. 1 is an end view of the girder before reinforcing, showing the original flange section composed of two angles per flange, without

*Reprinted from May 1938 issue *Civil Engineering*. Cuts furnished by *Civil Engineering*.

†Member American Society of Civil Engineers, Engineer of Metal Structures, Atlantic Coast Line Railroad, Wilmington, N. C.



Girder Span, Showing New Cover Plates and Additional Flange Plates and Rivets

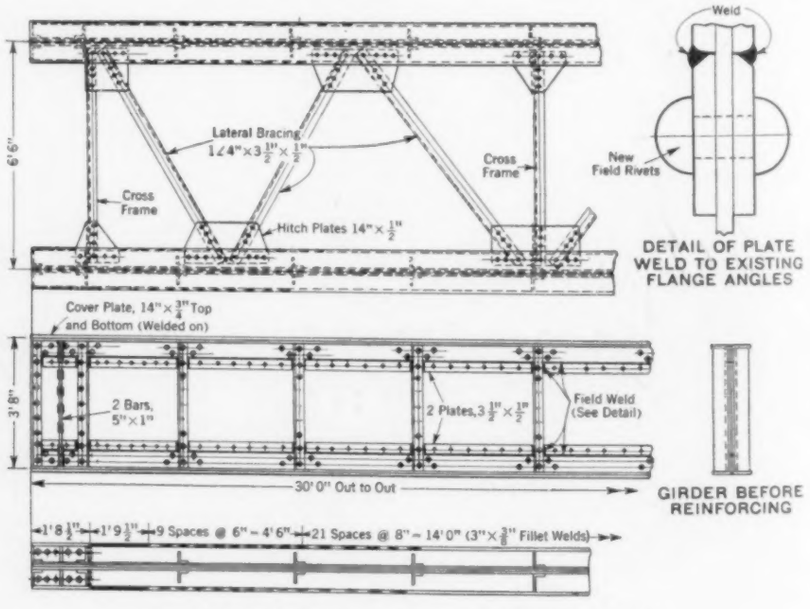

Weld
Lateral Bracing
1⌊4"×3½"×½"
Cross Frame
Cross Frame
New Field Rivets
Hitch Plates 14"×½"
6'6"
DETAIL OF PLATE WELD TO EXISTING FLANGE ANGLES
Cover Plate, 14"×⅜" Top and Bottom (Welded on)
3'8"
2 Bars, 5"×1"
2 Plates, 3½"×½"
Field Weld (See Detail)
30' 0" Out to Out
GIRDER BEFORE REINFORCING
1'8½" 1'9½" 9 Spaces @ 6" = 4'6" 21 Spaces @ 8" = 14' 0" (3"×⅜" Fillet Welds)

Fig. 1—Typical Reinforcement for a Deck Plate Girder Span

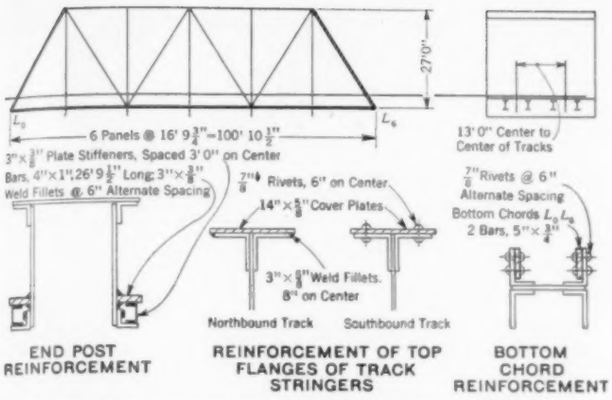

27'0"
L_0
L_6
6 Panels @ 16' 9 3/4"=100' 10 1/2"
13'0" Center to Center of Tracks
3"×3/8" Plate Stiffeners, Spaced 3' 0" on Center
Bars, 4"×1",26'9 1/2" Long; 3"×3/8" Weld Fillets @ 6" Alternate Spacing
7/8" Rivets, 6" on Center
14"×5/8" Cover Plates
7/8" Rivets @ 6" Alternate Spacing
Bottom Chords L_0 L_6
2 Bars, 5"×3/4"
3"×5/16" Weld Fillets. 8" on Center
Northbound Track
Southbound Track
END POST REINFORCEMENT
REINFORCEMENT OF TOP FLANGES OF TRACK STRINGERS
BOTTOM CHORD REINFORCEMENT

Fig. 2—Reinforcement for a Double-Track Through-Truss Span

cover plates. The deficiency in flange area (Item 1) was compensated by applying 14 by $^3/_4$-inch cover plates to the top and bottom flanges and securing them to the original flange angles by welding. Attention is called to the development in the strength of the new cover plates by continuous fillet welds at the ends, followed by intermittent interior fillet welds 3 inches long.

Before applying the top cover plates it was necessary to chisel out the daps in the wooden ties to allow for the additional flange width. This was done without disturbing the track. The entire deck was then raised off the top of one girder at a time, and the new top-flange plate was placed and firmly clamped to the flange angles. After lowering the deck onto the new plate, the same operation was carried out on the opposite girder. The weld fillets were then applied, the work proceeding without interruption except during the actual passage of trains. None of these steps involved any interruption to traffic.

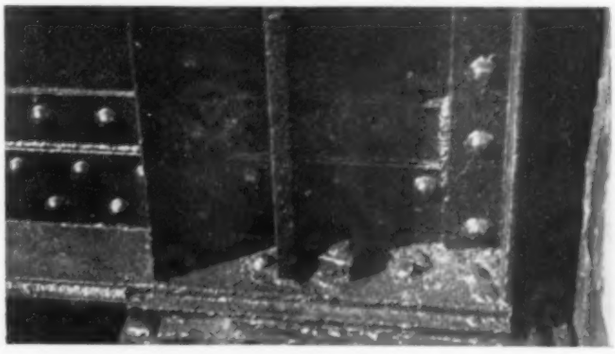
The new bottom cover plates were installed without difficulty. C-clamps were used to secure them to the original bottom-flange angles until the weld fillets had been completed.

The deficiency mentioned in Item 2 was made up by increasing the width of the vertical legs of the flange angles by means of $3^1/_2$ by $^1/_2$-inch plates, which were first riveted to the girder web and then welded to the upstanding leg of the original flange angles. Special care was taken to prevent the weld bead and the web from touching, as only by keeping them separated can the original flange-angle rivets be reinforced by the new rivets through the plates. The new plates were drilled at the bridge yard, and were used as templates for laying off holes in the girder webs that were drilled in the field.

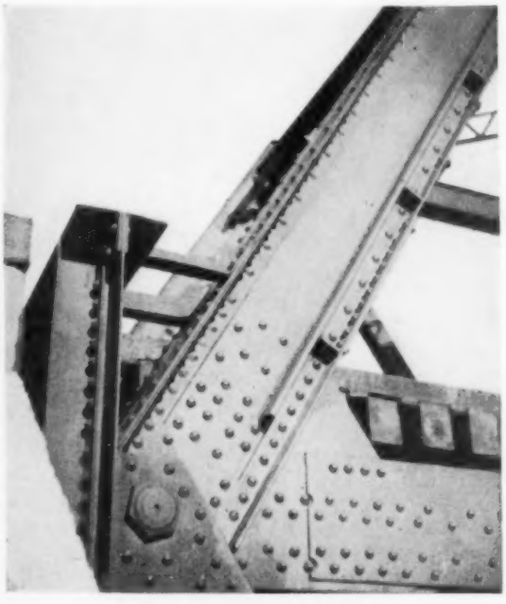
The deficiency in the end stiffeners (Item 3) was rectified by welding pairs of 5 by 1-inch vertical bars directly to each girder between the original end stiffener angles. The material for these bars came from a stock of eye-bars salvaged from pin-connected truss spans previously removed from service.

The renewal of top laterals and cross frames (Item 4) required the installation of heavier angles and plates than those originally used. Riveted connections were used because the original rivet holes were available in the girders, and because both welding machines were busy on other parts of the job. The track was jacked up between trains to provide clearance to drive the new rivets.

As a second example, let us consider the 102-ft. double-track through-truss span shown in Fig. 2. The computed stresses for the new locomotives showed that the span needed reinforcement in the bottom chords and in the inclined end posts. Field inspection showed also that the outstanding legs of the top-flange angles of the track stringers had bent downward under the ties. The material for reinforcing the bottom chords and end posts was taken from a stock of salvaged eye-bars. The material for repairs to the stringer flanges was new.



Reinforcement of End Stiffeners



Reinforcement of End Post

In Fig. 2 the end post, with reinforcing, is shown in cross section. A total of 8 sq. in. of section was added by means of the two 4 by 1-inch bars set edgeways against the web plates and stitch-welded in place as close to the bottom flange angles as possible. The 3 by $^3/_8$-inch plates serve as stiffeners to hold the reinforcing bars in position.

The bottom-chord reinforcement added 6 sq. in. net to each bottom chord. The 5 by $^3/_4$-inch bars were riveted, rather than welded, in order to develop the new material at the joints of the truss. Riveting of these plates left the welding machines free for the end-post reinforcement, and also permitted the new bars to be secured continuously across the joints. Splices were at points in the panels away from the joints.

The new cover plates on the tops of the track stringers provide an actual excess of metal. Their use is justified, however, (1) because the addition of the plates was made onto the top of the existing flange angles with no delay to traffic, and with no breaking of the track, and (2) because the $^5/_8$-inch thick plates were of such stiffness that the bent legs of the flange angles were pulled straight by the C-clamps or the fitting-up bolts. The 14-inch width of

the new cover plates provides the required width for weld beads on the lower side of the plate at each edge. Also, by projecting beyond the angles, the new plates protect them.

It will be noted that the plates added to the stringers on the northbound track were welded to the flange angles, while those on the southbound track were riveted. This permitted the work to progress simultaneously on the two tracks.

The reinforcement program outlined here was carried out under the direction of J. E. Willoughby, M. Am. Soc. C.E., chief engineer, Atlantic Coast Line Railroad.

Radiographic Inspection

By D. S. JACOBUS*

MR. ISENBURGER, in his recent paper Radiographic Inspection,† is certainly correct in saying that one of the greatest aids to the introduction of fusion welding for important work has been the development of nondestructive methods of testing.

Radiographing was the turning point in the development of sound and reliable welding and remains a most useful tool in the industry. All welded joints cannot, however, be radiographed and the question arises as to how far one should go in requiring this to be done.

The A. S. M. E. Boiler Code requires the main joints of the drums of power boilers and of unfired pressure vessels for hazardous services to be radiographed. Nozzle connections may, however, be fusion-welded to the same vessels without radiographic examination. In ship construction it would be impracticable to radiograph the joints and the use of fusion welding is nevertheless growing apace in this industry. The same holds in the manufacture of many other parts that are now joined by fusion welding.

Radiographing is regularly employed by some manufacturers as a check in securing sound welding even though it may not be called for by a construction code covering the work. It is useful in checking up welding operators when their work is questioned. It is generally conceded to be an invaluable aid in securing the highest type of construction as called for in the A. S. M. E. Boiler Code and in other cases, such as in the welded joints of large penstocks. While its merits are beyond question, there are certain welds where practice has advanced without its use.

It is the consensus of opinion that circumferential joints in the ordinary sizes of power piping need not be radiographed. The Code for Pressure Piping of the American Standards Association does not require the joints to be radiographed or tested by any method other than that sample joints shall meet certain physical tests.

The A. S. M. E. Power Boiler Code allows steam pipe not exceeding 14 in. inside diameter which is not in contact with the furnace gases to be fusion-welded without radiographic examination, but rigid qualification tests are required for the process and for the welding operators.

A number of authorities in marine construction are cooperating in preparing rules under the AMERICAN WELDING SOCIETY for the fusion welding of piping for marine use. As has been pointed out on a number of occasions, the hazard in marine steam piping is probably greater than in any other class of service. Those working on the rules appreciate this feature. In a tentative code which was published in THE WELDING JOURNAL for the purpose of eliciting discussion the welded joints are not required to be radiographed, provided they are inspected by the paramagnetic-powder method.

Considering all of the evidence before us, Mr. Corey is certainly correct in his conclusion** that X-ray examination of the welded joints in question should not be made mandatory.

O. R. Carpenter,‡ who has had extended experience in radiographing in field-weld inspection, holds the following views.

"The application of X-rays to field work has been retarded because of the lack of suitable equipment. The writer has on several occasions used equipment, similar to that described in Mr. Isenburger's paper, in the field. The positioning of such X-ray equipment (which includes a 150-lb. tube and case, long heavy high-tension leads, and a bulky heavy power plant) at the locations of field welds distributed throughout the circulating and feeder system of a boiler, for example, is difficult and at times impossible. No more portable X-ray apparatus than the present portable tube types has been devised and its uses for radiographic examination involves an expense at times in excess of the cost of welding and assembling the joint.

"Radium offers an easy solution to the objection of unportability of X-ray equipment. Mr. Isenburger makes mention of the use of radium for this purpose in his article, but stipulates that he does not prefer its use on wall thicknesses under $1^1/_2$ in. The reasons cited are the lack of contrast and detail due to the short wave length of gamma rays. The writer has during the past year taken more than 60 pipe welds ranging from $^3/_4$ in. to $1^1/_2$ in. thick with gamma rays. The capsule containing the radium salt or emanation gas may be placed on the inside of the pipe and the X-ray films around the outside of the weld. If the pipe is large enough, the capsule may be placed at the center of the girth weld with rays emanating in all directions from this central source, and the entire weld may be exposed with a single setting. For small-diameter pipe it is necessary to offset the capsule from this central position to provide a reasonable focal distance from capsule to film, and a number of exposures are necessary for a joint. Exposure time will vary with the strength of the available radium salt or emanation gas, with the thickness of the weld, and with the focal distance employed. With 100 mg. of radium salt and for normal pipe sizes, exposures will generally be from 5 to 15 min.

"In a recent case field welds were radiographed with radium using a 100-mg. capsule. The radiographs of welds in 8-inch and $10^7/_8$-inch O. D. pipe were taken in three exposures of from 5 to 8 min., covering one third of the circumference in each exposure; the wall thicknesses were $^7/_8$ inch and 1 inch, respectively. The welds in 16-inch and 20.4-inch O. D. pipe were taken in one exposure, with the radium at the center and the films covering the complete circumference. The shell thicknesses were $1^1/_4$ inch and $1^1/_2$ inch respectively, and the times of exposure 15 and 20 min."

While the use of radium may be preferable to the X-ray in certain cases, as brought out by Mr. Carpenter, this would not warrant making its use mandatory for conditions where practice has demonstrated the reliability of the welding without a radiographic examination.

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* Advisory Engineer, The Babcock and Wilcox Co.

† "Radiographic Inspection," by H. R. Isenburger, *Mechanical Engineering*, November 1937, pp. 809–812.

** *Mechanical Engineering*, March 1938, pp. 258–259.

‡ Research and Development Engineer, The Babcock and Wilcox Company, Barberton, Ohio.

Metallurgical Aspects of a Particular Type of Defect in Welded Material

By R. W. SANDELIN†

FACTORS determining the physical properties of a welded joint depend, among other things, upon the quality of the material being welded. Occasionally one will encounter failures of welds which more or less clearly indicate this fact. Examples of the particular type of weld failure described in this paper are illustrated by the use of the ordinary fillet weld used in the qualification of welding operators. The specimens shown in the following paragraphs represent $^1/_2$-inch plate arc-welded as shown in Fig. 1.

Figure 2 illustrates the normal type of fracture of a fillet weld used to determine such characteristics as degree of undercutting, nature of the fusion, appearance of the bead and others.

Fig. 1—Fillet Weld. Reduced $^1/_2$

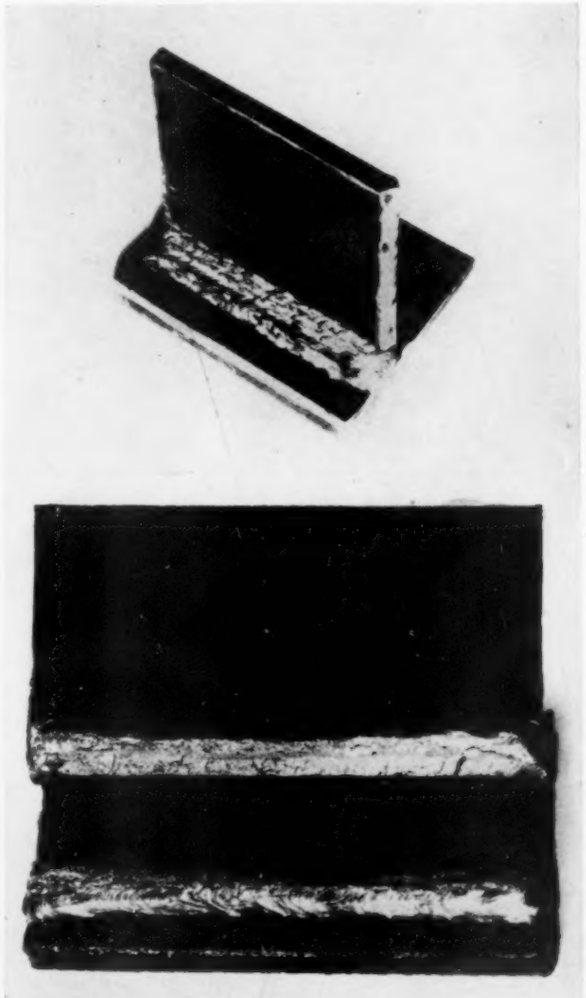
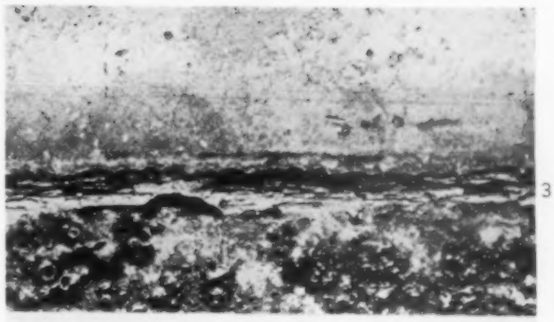


Fig. 2—Fillet Weld Broken for Examination. Reduced $^1/_2$

† Metallurgist, Atlantic Steel Company, Atlanta, Ga.



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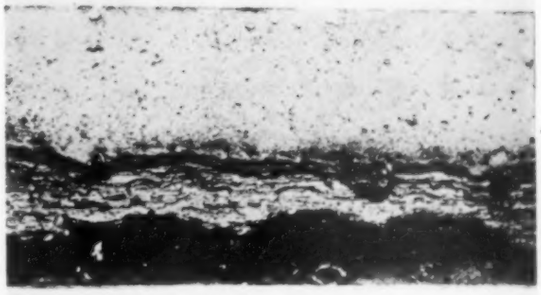

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Fig. 3—Top View of the Flat Used for Fillet Weld Test Specimen. Note the Manner in Which the Bead Pulled Out the Parent or Base Metal Leaving a Fibrous or Woody Fracture. Actual Size

Fig. 4—Another View Showing the Failure of the Base Metal. Actual Size

Fig. 5—The Weld in This Case Was Made Across the "Grain" Showing Again the Failure of the Base Metal. Note That the Fibrous Structure in the Fracture Occurs in the Same Direction as in the Fractures Shown in Figs. 3 and 4. Actual Size

In other cases, however, the fracture of the test specimen occurred not in the weld but in the base metal instead. The failure occurred by literally tearing out the material in the plate, giving the appearance of a "woody" or fibrous structure beneath. In every case the fibers occurred parallel to the rolling axis of the plate which incidentally was in the form of a flat of relatively narrow width when compared to its length.

Figures 3 and 4 show the weak fibrous structure where the weld had torn out. In the cases illustrated in Figs. 3 and 4, the weld was parallel to the axis of rolling. Figure 5 shows a weld failure where the fusion was made across the "grain" or fibrous structure, the fibers are seen to occur as usual parallel to the main axis of the flat material.

Figure 6 shows the part of the bead which pulled away from the other plate, having attached to it the fibrous, woody appearing material from the base or parent metal.

Fig. 6—The Fibrous Material Pulled Out of the Base Metal from One Plate Is Shown to Be Attached to the Bead Which Adhered to the Other Plate. Approximately Actual Size

Metallographic examination of this material revealed a microstructure reminiscent of wrought iron. Figure 7 shows a typical microstructure of this material viewed longitudinally to the axis of the flat, that is, parallel to the fibrous structure shown in Figs. 3, 4 and 5. Innumerable fine seams of nonmetallic material were readily detected. These threadlike seams were often of considerable length. Quite obviously the steel was extremely "dirty," the dirt being elongated in subsequent rolling processes to produce the weakened fibrous structure. A certain amount of banding of the ferrite and pearlite was observed but this was relatively unimportant when compared to the banding of such an excessive amount of nonmetallic matter which broke up the continuity of the ferrous material.

Ordinarily the occurrence of such dirty steel in present practice is quite rare. Occasionally, however, certain heats of semi-killed steel insufficiently cropped will give rise to such an inferior quality product.

The steel samples described above had the following analysis: Carbon 0.12%, Manganese 0.52%, Sulphur 0.029% and Phosphorus 0.018%.

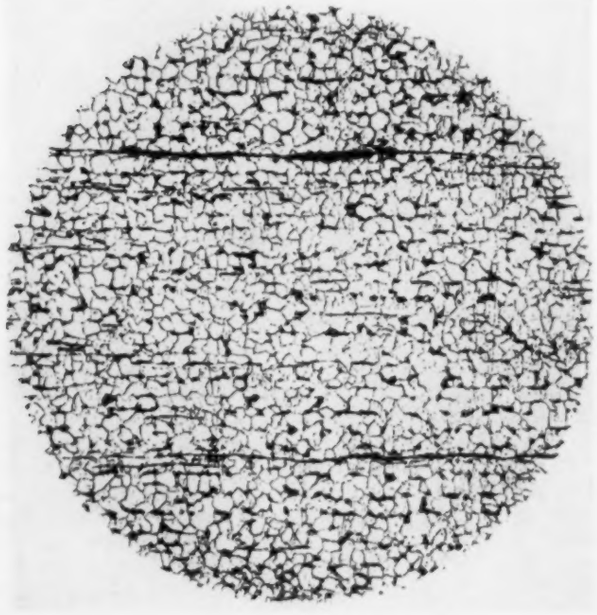

Fig. 7—Longitudinal View (Parallel to the Axis of Rolling) of the Base Material Which Produced the Fibrous Fractures. Note the Numerous Threadlike Inclusions of Nonmetallic Matter. ■ × 150

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Welding Aids in the Construction of Large Storage Tanks

By T. D. TIFFT†

PRIOR to a few years ago the standard large tank built was of 55,000 barrel capacity. More recently this standard has been increased to an 80,000 barrel tank and this size has become quite popular. Figure 1 illustrates a 150,000 barrel tank recently constructed for our Company by the Chicago Bridge and Iron Company. Figure 2 is a sketch drawn to scale outlining the three sizes of tanks mentioned above. The sketch indicates the growth in size in tank construction.

It would have been difficult to economically rivet these large tanks inasmuch as the large size rivets required would necessitate bull riveting and this operation is not well suited for field erection.

The dimensions of the large tank are 150 feet diameter, height 48 feet 3 inches. This tank is welded with six rings with plate thicknesses varying from a quarter to a little over one inch. Butt joints are used in the shell construction, welded from both sides.

† Sinclair Refining Company.

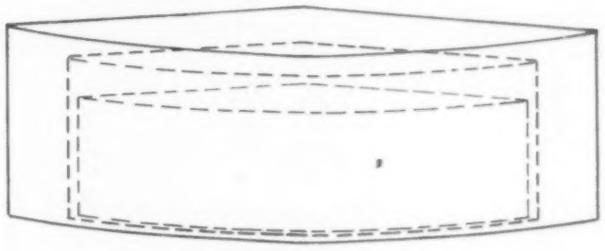

Fig. 2

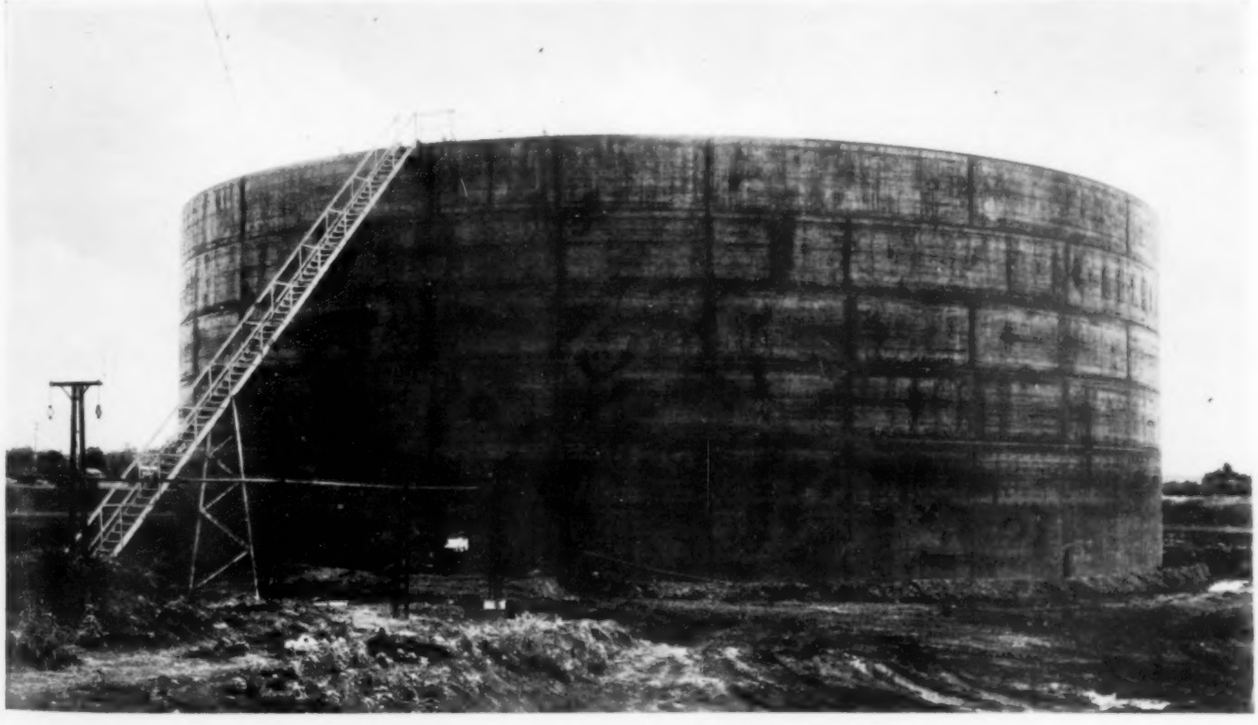

Fig. 1—A 150,000 Barrel Tank Constructed by the Chicago Bridge & Iron Co.

A. W. S. TENTATIVE RULES FOR

Welding of Oil Storage Tanks

Formulated by a
Committee on Rules for the Design and Construction of Welded Oil Storage Tanks

The AMERICAN WELDING SOCIETY

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PREFACE

To the Board of Directors,
AMERICAN WELDING SOCIETY

Your Committee, authorized and appointed at the 1933 fall meeting of the Society, has undertaken the task of drafting rules for the construction of welded oil storage tanks of the above ground type. The Committee has made an extensive investigation of this type of construction and has found that practice therein is now developed to a stage that renders it comparable to the art of riveted construction for such storage tanks. This conclusion is based upon the review of the data obtained from a large number of examples of successful welded storage tank construction, and it is upon this basis that the following draft of tentative rules has been formulated. These rules represent a cross section of the typical examples of good fusion welded construction and it is the belief of the Committee that if these rules are followed in the construction of this type of container safe and durable tank construction will result.

Committee on Rules for the Design and Construction of Welded Oil Storage Tanks
C. W. Obert, Chairman

J. J. Crowe	W. Samans
A. J. Deacon	E. E. Shanor
E. H. Ewertz	H. S. Smith
E. W. Fowler	H. A. Sweet
P. S. Graver	T. D. Tifft
G. Horton	E. Vom Steeg

D. C. Wright

SECTION I

Scope

These rules are intended to apply to the construction of fusion welded bulk storage tanks of the above ground type for holding oil and liquid petroleum products operating, generally, at atmospheric pressure. They are not intended to apply to tanks containing petroleum products that will produce a vapor pressure appreciably above a few ounces. The same general design of storage tank as herein referred to may be used for higher pressure purposes if a dome or umbrella-shaped roof is used and the shell is anchored to the foundation. The rules are written with special reference to the application of fusion welded construction to cylindrical tanks on vertical axes, but of such diameters that they cannot be shop constructed and shipped by cars or trucks. They are intended to prescribe safe requirements for such welded tanks.

These rules have been formulated with the assumption that the tank will be placed upon a suitable foundation and that it will not be subject to settlement or deformation to the extent of causing excessive concentration of stresses.

These rules were prepared at the request of the National Board of Fire Underwriters and are to supplement Tentative Standards No. 12-C of the American Petroleum Institute, edition of October 1937 (as amended by Supplement No. 1 of April 1938), which cover general features of design, fabrication and erection of such bulk storage tanks.

SECTION II

Definitions and Symbols

Terms relating to fusion welding and symbols used are based upon the latest Report of the A. W. S. Committee on Nomenclature, Definitions and Symbols, and construction drawings should conform thereto.

SECTION III

Materials

A. *General*

All material entering the construction of tanks covered by this code shall comply with at least the minimum requirements of some one of the following Material Specifications, provided the carbon content does not exceed 0.35 per cent and all rolled plate material is of open-hearth stock. If the material has a minimum tensile strength less than 55,000 lb. per sq. in. the allowable fiber stress shall be reduced by an amount equal to the ratio of its minimum strength to 55,000. If other materials of weldable quality are made available, their specifications may be submitted to the AMERICAN WELDING SOCIETY for consideration under these Rules.

B. *Material Specifications for Base Metal*

1. All rolled plate steel used in shell, bottom, roof, nozzles and reinforcements and all structural materials involved therewith shall conform to one of the grades embraced under the American Society of Testing Materials' general specifications for carbon steel for fusion welding designated as A. S. T. M.-A-151, but no Bessemer material is acceptable, and the carbon content of the material shall not exceed 0.35 per cent.

2. Forgings used in nozzles and reinforcements shall conform to one of the following A. S. T. M. specifications:

A-78 —Specifications for steel plate—structural quality for forge welding (Grades A and B).
A-105—Specification for forged or rolled pipe flanges for high temperature service (Classes A, B and C).
A-181—37-Specifications for forged or rolled steel pipe flanges for general service (Class 1).

3. Steel castings shall conform to one of the following A. S. T. M. specifications:

A-27 —Specification for steel castings.
A-95 —Specification for carbon steel castings (carbon limited to 0.35 per cent).

C. *Material Specifications for Filler Metal.*

All filler metal shall comply with the A. W. S. Tentative Specifications for Filler Metal for Use in Fusion Welding, Grades 2, 4, 10, 15 or 20.

SECTION IV

Qualification of Welding Processes and Testing of Operators

Welding processes shall be qualified and welding operators shall be tested according to the latest Rules of the AMERICAN WELDING SOCIETY for Qualification of Welding Processes and Testing of Welding Operators, using the following values:

Butt Welds

(*a*) *Tensile Test.*—Reduced section tensile test.....not less than 95 per cent of the minimum of the specified tensile range of the plate used.
(*b*) *Free-Bend Test, min*.....20 per cent.
(*c*) *Root Break, Side Break, Nick Break.*—Porosity not to exceed 6 gas pockets per sq. in. of total area of weld surface exposed in fracture, the maximum dimension of any such pocket not to be in excess of $^1/_{16}$ inch.

Fillet Welds

(*d*) *Shear Test.*—Longitudinal or Transverse Shear Test.....not less than 80 per cent of value of (*a*).
(*e*) *Fillet Weld Break*.....same as (*c*).

SECTION V

Design

1. *Minimum Thickness*

The minimum thicknesses of plate used for construction of field-erected tanks shall be as follows:

Shell plates in tanks up to 48 feet diameter..$^3/_{16}$ inch
Shell plates in tanks over 48 feet diameter..$^1/_4$ inch
Bottom sketch plates in tanks up to 48 feet diameter.....$^1/_4$ inch
Bottom sketch plates in tanks over 48 feet diameter.....$^5/_{16}$ inch
Rectangular bottom plates for all sizes of tanks.....$^1/_4$ inch

2. *Shell Joints*

The vertical or horizontal joints of the shell may be of the following types:

(*a*) Double-welded butt type;
(*b*) Single-welded butt type with backing-up strip or equivalent means to insure complete penetration;
(*c*) Double full-fillet lap-welded type, with the plate edges lapped not less than 5 *t*, up to and including a maximum plate thickness of $^7/_{16}$ inch.
(*d*) Single full-fillet lap-welded type, with the plate edges lapped not less than 5 *t* and the inside lap welded at least 25 per cent intermittent (seal welding may be applied to the inside lap in place of the intermittent welding).

In vertical shell joints, type *d* is permitted only in plates up to $^1/_4$ inch thickness, inclusive. Butt joints may be welded without beveling the edges provided the thickness does not exceed $^1/_4$ inch. The plate edges must be separated where necessary to obtain complete penetration and thorough fusion. The beveling may be performed in horizontal joints, on the lower edge of the upper plate, provided the angle of bevel is not less than 45 degrees.

3. *Loads and Working Stresses*

Stresses are to be computed on the assumption that the tank is filled level full of water at 60° F., and the tension in each ring is to be computed 12 inches above the center of the bottom weld of the ring in question. The working tensile stress applied to the steel plate comprising the shells, shall not exceed 21,000 lb. per sq. in.*

4. In computing the minimum thickness of the shell plates required, the joint shall be rated as follows:

(*a*) Type *a*.....85 per cent
(*b*) Type *b*.....85 per cent
(*c*) Type *c*.....70 per cent
(*d*) Type *d*.....$50 + k/5$

Where *k* is the percentage of full fillet intermittent welding.

5. *Butt-Welded Vertical Joints*

These seams shall be welded to insure complete penetration and fusion. Plates up to and including $^1/_4$ inch thick may be butt welded without beveling the edges of plates, the gap, if used, between adjoining edges to be not less than one-half the plate thickness. Plates over $^1/_4$ inch and up to $^7/_{16}$ inch thick, inclusive, may be double beveled, if desired, or need only be beveled from one side of the plate, with the included angle between the sloping edges of the plate at the joint not less than 60 degrees; the gap, if used, between adjoining edges to be $^1/_8$ inch. Plates over $^7/_{16}$ inch thick shall have double beveled or U-grooved edges, the gap between adjoining edges to be $^1/_8$ inch. For single or double U-welded butt joints, the angle formed by the straight faces of the U on the adjoining edges to be welded together, shall be not less than 15 degrees. The reinforcement on the weld shall not be taken into account in the strength computations.

* When in the opinion of the authorities having jurisdiction, a lower design tensile stress is necessary than is specified herein, it is suggested that a maximum tensile stress in design not lower than 18,000 lb. per sq. in. be used. The minimum shell plate thicknesses specified in these Rules will usually provide this lower stress in tanks of the sizes commonly used in bulk oil stations used for distribution service.

6. *Butt-Welded Horizontal Joints*

These joints shall be welded to insure complete penetration and fusion. Plates up to and including $^1/_4$ inch thick may be welded together without beveling the edges of plates, and with or without a gap between adjoining plate edges. Plates over $^1/_4$ inch and up to $^7/_{16}$ inch thick, inclusive, may be double beveled, if desired, or need only be single beveled, in which case the lower edges of the upper plate are beveled to an angle of 45 to 60 degrees with the joint face leaving a width of square edge not over one-quarter of the plate thickness; the upper edge of the lower plate is left square, and with or without a gap between adjoining plate edges: the reverse side of this joint to be rewelded for seal and finish, but no chipping out of applied weld-metal is required, except for repairs referred to in Section IX. Plates over $^7/_{16}$ inch thick shall have double-welded butt joints, in which the lower edges of the upper plate shall be beveled from both sides of the plate at an angle of 45 to 60 degrees from the middle transverse line of the joint, leaving a width of square edge not over one-quarter of the plate thickness, and with or without a gap between the adjoining plate edge.

7. *Lap-Welded Vertical Joints*

Vertical lap joints shall have continuous full-fillet welds both inside and outside, except that on plates up to and including $^1/_4$ inch thick, they may have a continuous full-fillet lap weld on the outside, and the inside fillet weld at least 25 per cent intermittent. A continuous full fillet or seal weld may replace the intermittent welding. Lap joints shall have the overlap not less than 5 t or 1 inch, whichever is larger. The maximum plate thickness permissible with a double full-fillet lap type in a vertical joint shall be $^7/_{16}$ inch.

8. *Lap-Welded Horizontal Joints*

Horizontal lap joints shall have the overlap of the plates not less than 5 t or 1 inch, whichever is larger. The fillet on the top edge of the lower plate to be full-fillet lap weld, measured along the edge of one plate and the surface of the other plate. The fillet on the bottom edge of the upper plate to be at least 25 per cent intermittent. Continuous fillet welding smaller than full fillet but equivalent in strength to the full fillet intermittent welding may be applied in place of the intermittent welding. With intermittent welds, apply continuous welds for 6 inches on each side of the vertical seam. All horizontal welds between shell and bottom plate and along any intermediate bottom angle or other rolled structural member shall be continuous.

9. *Openings and Reinforcements*

Openings over 4 inches in diameter in the shell of a tank shall be reinforced. The required reinforcement may be provided by the attachment flange of the fitting, by an additional ring serving as a nozzle neck, and/or by a reinforcing plate placed around the opening to distribute the stress to the shell plate.

10. The strength of the required reinforcement around an opening in a shell plate shall be based on the vertical cross-sectional area of the metal removed from the plate. This area shall be taken as the product of the vertical diameter of the hole cut in the shell plate, the thickness of this plate and the efficiency factor in Par. 4, for the type of vertical joint in this plate. The strength through the net cross-sectional area of the reinforcement added, lying in a vertical plane (plane of reinforcement) coincident with the axis of the opening, shall at least equal that of the above product.

11. In computing the net cross-sectional area of reinforcement for an attached fitting such as a boilermaker's flange, or a flanged nozzle or a ring serving as a nozzle neck, or a manhole, the neck may be considered as part of the area of reinforcement, but only for a length of four times the thickness of the wall of the neck, measured outward and/or inward from the nearest surface of the shell plate or that of an intervening reinforcing plate.

12. The aggregate strength of the welding attaching a fitting to the shell plate and/or any intervening reinforcing plate shall at least equal the proportion of the stress passing through the entire reinforcement, that is computed to pass through the fitting considered.

13. The aggregate strength of the welding attaching any intervening reinforcing plate to the shell plate shall at least equal the proportion of the stress passing through the entire reinforcement, that is computed to pass through the reinforcing plate considered.

14. The strength of the welding for attachment of reinforcements may be taken as the total shear resistance of the fillet welds that are applied on either side of the plane of reinforcement. This shear resistance shall be computed as 11,300 lb. per sq. in. of cross section measured in the throat of the weld, for end welds, and 75 per cent of this value for side welds. The throat of a fillet weld shall be assumed as 0.707 times the shortest leg of the fillet weld. If circular or diamond shaped reinforcing plates are used, the 75 per cent factor shall be applied.

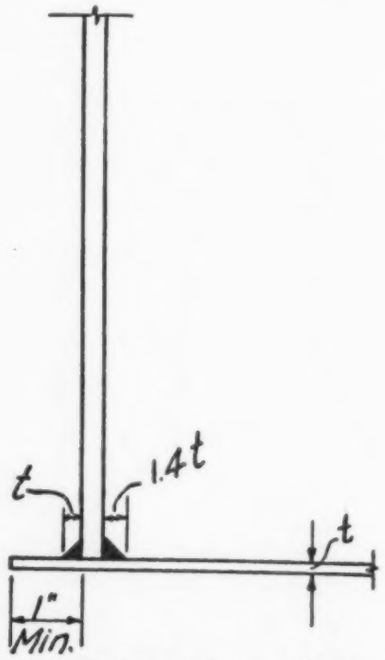

Fig. 1 **Welded Joint at Junction of Shell and Bottom Plates**

15. *Joints at Junction of Shell and Bottom*

The attachment between the bottom edge of the lowest shell plate and the bottom plates may be made by means of a ring angle with all welds continuous, or the bottom edge of the shell plate may be continuously fillet welded to the bottom plate on the inside and outside.

In the case of the fillet welded attachment of the sheet direct to the bottom plate, as shown in Fig. 1, the inside fillet shall have a minimum leg of not less than 1.4 times the thickness of the bottom plate. The outside fillet shall have a minimum leg of a dimension not less than the thickness of the bottom plate. If the lowest shell plate is thinner than the bottom plate, as in small tanks, the factors 1 and 1.4 shall apply to the thinner plate.

16. *Bottom Joints*

The joints between the plates forming the bottom of the tank may be of single welded butt type with backing-up strip, or of the single welded lap type, provided the overlap is not less than 5 t or 1 inch minimum. Butt joints may be welded without beveling the plate edges provided the thickness does not exceed $^1/_4$ in. The plate edges must be separated if necessary to obtain complete penetration and thorough fusion.

SECTION VI

Fabrication

Preparation for Welding

1. The plates may be cut to size and shape and formed by machining or shearing, or by flame cutting. The edges must be uniform and smooth and must be freed of all loose scale and slag accumulations before welding. The discoloration which may remain on the flame-cut surface is not considered to be detrimental oxidation.

2. The plates or sheets to be joined shall be suitably shaped and formed.

3. Particular care should be taken in the layout of joints in which fillet welds are to be used so as to make possible the fusion of the weld-metal at the bottom of the fillet. Great care must be exercised in deposition of the weld-metal so as to secure satisfactory penetration.

4. At all lap joints the plates shall be held in close contact during the welding operation. Plates in which the vertical joints are to be butt welded shall be accurately matched and retained in position during the welding operation with a tolerance of 10 per cent of the plate thickness but not more than $^1/_{16}$ inch for plates over $^5/_8$ inch thick on the finished work.

5. In horizontal butt joints plates may be aligned by any effective method but after welding is completed the upper plate shall at no point project beyond the face of the lower plate by more than 20 per cent of the thickness of the upper plate with a maximum of $^1/_8$ inch projection.

6. Bars, jacks, clamps or other appropriate tools may be used to hold the edges to be welded in line. The edges of butt joints shall be so held that they will not overlap during welding. Where fillet welds are used, the lapped plates shall fit closely and must be kept tightly together during welding.

7. The surfaces of the sheets or plates to be welded shall be cleaned thoroughly of all objectionable scale, rust, oil or grease for a distance of not less than $^1/_2$ inch from the welding edge. Grease or oil may be removed with gasoline, lye or the equivalent. A steel-wire scratch brush may be used for removing light rust or scale, but for heavy scale, slag and the like a grinder, chisel, air hammer or other suitable tool shall be used to obtain clean and bright metal. When it is necessary to deposit metal over a previously welded surface, any scale or slag therefrom shall be removed by a roughing tool, a chisel, an air chipping hammer or other suitable means to prevent inclusion of impurities in the weld-metal.

8. The dimensions and shape of the edges to be joined shall be such as to allow thorough fusion and complete penetration.

9. If the welding is stopped for any reason, extra care shall be taken in restarting to get full penetration to the bottom of the joint and thorough fusion between the weld-metal and the plates, and to the weld-metal previously deposited.

10. Where single-welded butt joints are used, particular care shall be taken in aligning and separating the edges to be joined so that complete penetration and fusion at the bottom of the joint will be assured.

11. Where butt-welded vertical joints are used with lap-welded girth joints, care must be taken to obtain complete penetration and thorough fusion in that part of the butt weld which is covered on one side by the lap.

SECTION VII

Erection

An Erection Note for Butt-Welded Construction

1. When butt welding is employed for joining shell plating, the welding procedure therefore shall be so devised that undue welding stresses, generally referred to as "residual welding stresses," are not allowed to develop in the plating about the welded joint. These stresses are additive and if allowed to develop (a possibility when the plating is rigidly affixed to its adjoining plates such as when firmly tack-welded) may, in extreme cases, cause a lowering of the factor of safety of the joint. A plate should be free to move to accommodate the contraction about the cooling weld, or advantage may be taken of the curvature of the plate to relieve residual stress. In any case, movement shall be provided so that plates shall not be rigid against these known forces.

2. The sub-grade must be properly prepared, surface vegetation removed and preferably sand, or clay and sand surface coating spread over the area to be occupied by the tank, and so graded that it will be well drained. In some locations, and particularly for the smaller tanks, the entire surface may be level, provided it is a few inches above the surrounding grade.

3. It is recommended that a sequence or order of welding the seams joining the bottom plates be followed that will result in the least distortion due to shrinkage in the welding, and thus provide, as nearly as possible, a plane bearing surface.

SECTION VIII

Inspection

1. *Inspection and Tests of New Welded Storage Tanks*

Welded tanks constructed under these Rules shall be inspected and tested in accordance with the following paragraphs. A definitely designated inspector shall follow the qualification tests of the welding operators, the fabrication, erection and testing of each tank and shall make sure that material, details of design, fabrication and tests called for in this Code are complied with.

2. *Qualification of Inspectors of Welding*

Inspectors shall be competent men experienced in welding and supervision of welding, checking and testing of welding operators. Inspectors shall be employed by the Purchaser or by an organization regularly engaged in making inspections, except that they may be employed by the Contractor with the approval of the Purchaser when a definite guarantee is furnished by the Contractor to the effect that these Rules, with all its requirements, will be met.

3. *Access for Inspector*

The inspector shall be permitted free access to all parts of the Contractor's plant concerned with the fabrication of the tank, and to the site at which the tank is being erected during its fabrication, erection and testing.

4. *Facilities for Inspection*

The Contractor shall afford the inspector all reasonable facilities for testing and inspection and keep him informed of, and shall permit his presence at, all tests of material and welding during fabrication and erection; this shall include all hydrostatic tests of the tank and all laboratory tests of the welding and of the material used.

5. *Inspection of Plates*

The inspector shall inspect the plates used in the construction of each tank, giving particular attention to all cut edges and openings to assure that the plate is free from laminations or other defects. The plates shall be gaged or measured to determine whether the thickness meets the requirements of these Rules.

6. *Qualification Tests*

The inspector shall make sure that the welding process used by the contractor has been qualified in accordance with the Rules for Qualification of Welding Process. If any doubt as to this Qualification of Welding Process arises, the inspector may require the official records of this Qualification Test be produced for his check. The inspector shall check the records of the Qualification Tests of Welding Operators and shall, if necessary, require new or periodic Qualification Tests of Welding Operators. No welding operator shall be permitted to work until the inspector is satisfied regarding his qualification.

7. *Welding*

Inspection of the tank construction shall be made at the time the principal joints are being welded. The inspector shall check the plates to see that they are properly fitted and retained in position during welding, that the edges are properly prepared and aligned, and that the welding conforms to the requirements of this Code. He shall see that the assembly and welding procedure are such as to prevent excessive flattening or buckling during welding.

8. *Approval of Inspector*

The approval of the inspector shall be required before any defects are repaired. Defective material that cannot be satisfactorily repaired shall be rejected.

9. *Hydrostatic Test*

The inspector shall witness the making of hydrostatic or other tests as required by this Code. Where repairs are necessary the inspector shall see that the defective welding has been properly cleaned out before permitting the defective portions of the tank to be rewelded.

10. *Inspector's Final Report*

The inspector shall at the completion of all tests and inspection prepare a report summarizing all data on the tank which have been compiled. Copies of this report shall be transmitted to the Purchaser and the Contractor for their records.

SECTION IX

Testing

1. Upon completion the entire tank shall be tested by filling preferably with water to the level of the top angle.

2. Repairs of defects discovered after tank is filled for test shall be made only under the following conditions:

(*a*) Joints shall be repaired with water level at least 1 foot below the point being repaired, or with the tank empty if repairs are on or near the tank bottom.

(*b*) No welding shall be done on any tank unless all pipe lines connecting thereto have been completely blanked off. No welding repairs shall be permitted on any tank that has been filled with oil until tank is emptied and washed out and/or steamed out, or otherwise gas freed in a safe manner.

3. For the purpose of testing the tank bottom after it is welded up, various methods are available as follows:

(*a*) Dam up the edges of the tank using wet clay or some other suitable closure, and pump air under the bottom, then soapsud the seams. Linseed oil may be used on the seams.

(*b*) Pump water under the bottom after the edge has been dammed up.

(*c*) Pump penetrating oil under the bottom. If some type of penetrating oil is used, it is believed that the ground should first be saturated with water so that the oil will have a tendency to float on top.

(*d*) First surface the grade with asphalt, if available. This will not only protect the underside of the bottom from moisture, but it will also serve to keep the oil, water or air, which is pumped under the bottom, from being absorbed by the ground.

GENERAL NOTE: No method of test will improve unsatisfactory welding, and it is all important that all portions of all bottom seam welds should be inspected over every inch of their length with great care and thoroughness.

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Welding Society ACTIVITIES — Related Events

CHANGE IN HANDBOOK PRICE

Effective September 1, 1938, the price of the Handbook to Associate, Operating and Student Members will be increased from $2.50 to $4.00. The original price was set when it was thought that the Handbook would consist of 600 pages. The book as issued is over 1200 pages. Complimentary letters being received daily indicate that this book, without question, will be accepted as the world's leading authoritative book on welding.

ALL-WELDED TANKER

A contract for construction of a third 18,500 ton all-welded, turbo-electrically driven tanker for The Atlantic Refining Company has been let to the Sun Shipbuilding and Dry Dock Company, Chester, Pa., Atlantic officials announced today. The vessel is to be a sister ship to the "Robert H. Colley," which will be launched from the Sun Shipyards at Chester this Saturday, and the "J. W. Van Dyke," which has been in service between the Texas Gulf ports and Philadelphia since February.

Construction of the new vessel at an estimated cost of $2,500,000 is another step in Atlantic's $28,000,000 expansion and development program for 1938, announced last May. The new vessel, scheduled for delivery in January 1940, will give the Atlantic fleet the three largest turbo-electric ships of welded construction in the world.

THE ROBERT H. COLLEY

The Atlantic Refining Company's 18,500-ton tanker, the "Robert H. Colley," was launched at Chester, Pa., July 9th, at the yard of the Sun Shipbuilding and Dry Dock Company. The new vessel was christened by Mrs. Robert H. Colley, wife of the president of The Atlantic Refining Company, for whom the latest addition to the company's tanker fleet is named. The "Robert H. Colley" and her sister ship, the "J. W. Van Dyke," launched in November 1937, are the world's largest welded ships.

Overall length of the new tanker is 541 feet five inches. Cargo capacity is 6,552,000 gallons. Turbo-electric engines are designed to develop 5000 horsepower and will give her a speed of 13.25 knots. She has a molded beam of 70 feet, a molded depth of 40 feet, and a draft of

The S. S. "Robert H. Colley" Leaving the Ways at the Yard of the Sun Shipbuilding and Dry Dock Company, Chester, Pa.

29 feet seven inches. Capacity of the fuel oil bunkers is 380,940 gallons. The new vessel is scheduled to go into service in August, on the run between Philadelphia and Texas Gulf ports.

Robert H. Colley, whose name the new ship bears, entered the employ of The Atlantic Refining Company in 1919. He was elected treasurer, and a director of the company, in 1929. Elected a vice-president of the company in 1936, his election as president took place on May 4, 1937. During the World War he served as an artillery officer with the U. S. Army in France.

WELDED HOSPITAL BUILT WITHOUT NOISE IN 58 WORKING DAYS

Freed from the machine-gun rattle of the rivet hammer, the 13-story Woman's Hospital of Pittsburgh has risen silently during 58 noiseless working days in the midst of the University of Pittsburgh's Medical Center. In fact, the 1000 tons of steel for Pittsburgh's first arc-welded building were joined to the new Presbyterian Hospital; less than 200 feet away are the Eye and Ear Hospital and the Children's Hospital. The staccato beat of riveters was the last thing the physicians would prescribe for the hundreds of patients in these hospitals.

To meet the stipulation of the Woman's Hospital board of directors that the structure be welded together, City Council granted a special construction permit pending passage of a new ordinance incorporating welding regulations in the building code.

Electric Power Eliminates Rivets

Ordinarily 15 tons of rivets would have been pounded into the steel framework, but the welders substituted $300 worth of electric power to merge 2300 pounds of welding rods with the structural steel which was manufactured by the Bethlehem Steel Corporation. The Duquesne Light Company installed power service for the transformer type arc welders eliminating need for motor-driven or engine-driven direct current welding machines.

The inherent strength of the arc welds eliminated use of enough plates and connecting angles to equal the steel required for one additional floor.

Welded Columns Support Erection Derrick

Putting the structural strength of welds to a titanic test, the builders used the welded columns and beams to support the largest steel erector's derrick ordinarily used on building construction, a 110-foot mast with a 100-foot boom, capable of hoisting six-ton loads in a single lift.

Stone and Webster Engineering Corporation, managing the construction, selected as the steel contractor the John L.

Silent Workers

Use of alternating current arc welding enabled the builders to erect the new Woman's Hospital next door to three other hospitals. In the background can be seen the recently completed Presbyterian Hospital in the University of Pittsburgh's Medical Center. (Westinghouse Photo.)

Noiseless Construction

The 13-story Women's Hospital of Pittsburgh rose in the University of Pittsburgh's Medical Center, its 1000–2300 pounds of welding rods supplanted 15 tons

Welds for Rivets

of rivets in construction of the new Woman's Hospital of Pittsburgh. This masked welder is joining two beams. The bolts in the forefront temporarily hold the steel in place while electricity merges the two pieces

Mullen Construction Company, erectors of the steel frame of the world's first multi-story alternating current arc-welded structure, the new office building at the transformer works of the Westinghouse Electric & Manufacturing Company in Sharon, Pa.

Safety Without Noise

"There's no noise at all; that's the first paradox that impresses the builder using arc welding," commented Mr. Mulvehill, president of the Mullen concern. "At first, it doesn't seem possible that metal can tie itself together, but test after test have proved that the welded joints are as strong as the steel itself."

To insure a perfect structure, all welders were qualified by the Pittsburgh Testing Laboratory, which supervised tests under the AMERICAN WELDING SOCIETY Rules. Mr. Whiting, of the testing laboratory, supervised field tests and inspection on welds as they were applied on the building. He reported: "We took samples of hundreds of welds and found them as permanent as the building itself."

When completed within the next year, the Woman's Hospital will be one of three in the entire country devoted exclusively to a study and treatment of diseases peculiar to women. In addition to the laboratories and therapeutic rooms, its six hospital floors will accommodate 150 patients.

Mr. Richard K. Mellon is president of the hospital board. Other board members and officers include Dr. Sidney A. Chalfant, vice-president, Mr. John F. Tim, secretary-treasurer, and Mr. James A. Dunn.

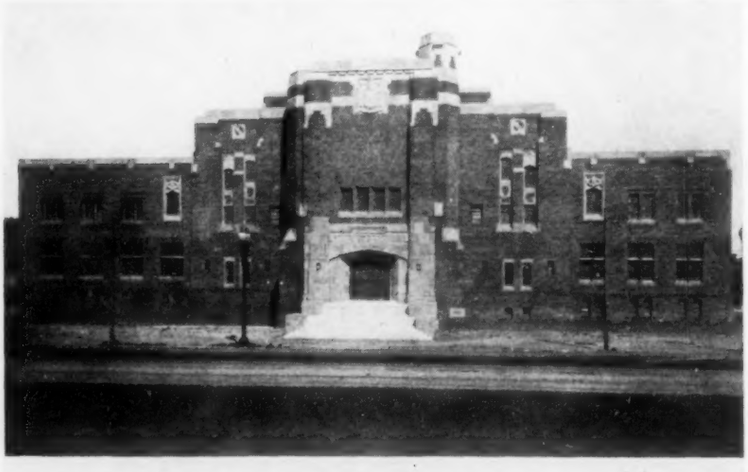
N. Y. STATE TAKES OVER ALL-WELDED ARMORY

After a final inspection of the new state armory at Schenectady, N. Y. recently by the adjutant general of New York State, the all-welded steel and brick structure was turned over to local companies of the National Guard. The building, one of the largest all-welded frame structures in upstate New York, was completed after two years of construction involving such preliminary work as the rerouting of a main storm sewer outlet and the driving of more than 900 large piles in the subsurface. The selection of welding as a construction tool was a happy one, not only because of the economies it afforded but because the building is located in the immediate vicinity of a large hotel and the quietness of the welding operations was an appreciated factor. The completed armory, which has an area of 26,300 square feet of unobstructed floor space in the drill hall alone, was arc welded.

One of the outstanding points of interest from a construction point of view is the huge 92-foot roof plate-girder supporting the structure above the balcony which looks down on the drill floor. Other noteworthy features include seven 150-foot-span, two-hinged main roof arches and continuous all-welded steel framing for supporting the drill-shed floor.

SEVEN MILES OF WELDING IN THE SUGAR BOWL

Approximately seven miles of welding went into the recent addition to the Sugar Bowl, Tulane University's stadium where championship football teams battle for supremacy each New Year's Day. The Dixie Machine Welding and Metal Works, which received the contract for the actual welding work, finished the job in record time, using six 400-ampere electric welding equipments. Because of its welded steel construction, it is estimated that the addition cost approximately $60,000 less than a comparable reinforced concrete structure.



Welded Armory—(Top) Completed Building. (Bottom) Arc-Welded Frame

LARGEST ALL-WELDED STEEL DUMP SCOWS

Two of the largest all-welded steel dump scows ever to be built in an inland waterways shipyard have just been launched by the Dravo Corporation at its Neville Island yards for use on the Great Lakes.

Both dump scows were built for Merritt-Chapman & Scott Corporation, New York, in record time, and will be used on Lake Erie at Conneaut, Ohio, in connection with the Great Lakes Waterway Improvement Program. This program calls for the deepening of Conneaut Harbor, and the scows will be loaded with the material dredges from the harbor bottom, towed to deep water and dumped.

The scows have a capacity of 1200 cubic yards and measure 206 feet by 40 feet by 14 feet. Over 650 tons of steel were required for fabrication of each vessel.

Original plans for the scows were made up with the idea of riveted construction. However, Dravo Engineers realized that an all-welded construction would lead to an increased efficiency in the use of the steel required, would result in a general over-all decrease in weight, and would provide considerable cost saving. For these reasons, the plans were redrawn and the vessels built by welding.

Launching of All-Welded 1200 Cubic Yard Dump Scow at Dravo's Neville Island Yards

View of Hopper Door Operating Mechanism. Note Shafts and Power Chains

Each scow contains nine hopper pockets 17 feet long, 25 feet wide at the top, and 13 feet wide at the bottom. The pockets are equipped with two hopper doors built up of composite timber and steel, using heavy oak timber fills between 10-inch and 12-inch I Beams. Hopper bulkhead fenders and coaming fenders on the loading side of the scow are concrete filled. The hopper doors are operated by a six inch by six inch throttle reversing steam engine, the engine being connected to a ratchet arrangement on a steel jack shaft. Steam is provided by the towing tug. The ratchets, in turn, revolve a gate operating shaft and are so arranged as to permit the independent opening and closing of the hopper gates. Solid weld power shovel chains run from the gate operating shaft to double-cable slings, which pass through guide castings to the doors. Chains are tested to a breaking strength of 175,000 pounds. Release of a pawl opens the doors by gravity and the weight of the load.

At each hopper separation, water-tight bulkhead divisions are provided throughout the length of the scows, forming individual buoyancy tanks. One 16 inch by 20 inch manhole is provided for each water-tight compartment. Both rake ends contain separate water-tight rooms for storage of lines and equipment. These rooms measure 6 feet by 10 feet and are placed on the operating side of the vessel. Fully loaded, the scows will draw about 12 feet 6 inches.

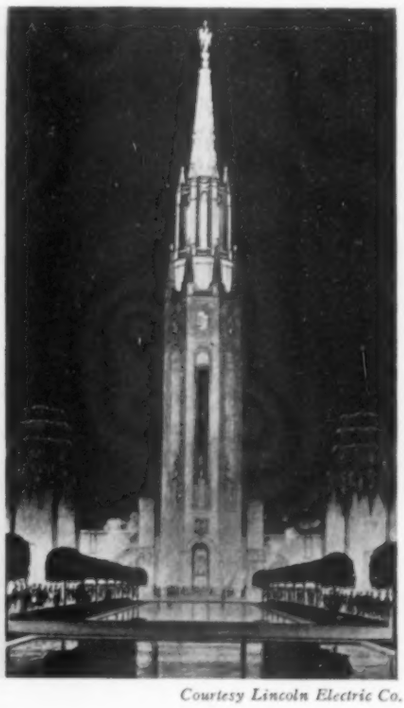
In order to deliver the scows to the site of operations, which by land is about 120 mile distant, it will be necessary to tow them nearly 2300 miles from Pittsburgh to the Mississippi River, through the Illinois Waterway to Chicago, and from Chicago through Lake Michigan, Lake Huron and Lake Erie to Conneaut, Ohio.

PHOENIX

Gigantic Phoenix, fabled offspring of its own ashes, takes shape in "fire" that is 7000 degrees hot—the flash of the electric welding arc. (see illustration below)

Golden symbol of San Francisco's rise from its own ashes following the disastrous fire of 1906, this 5000 pound 22-foot monster is made up of 700 separate, hand-shaped 16-gage metal sections fused together into one single piece by 6800 linear feet of shielded arc welding. It has a surface area of 680 square feet and is one of the largest hand-hammered wrought iron figures ever fashioned. Use of electric arc welding, made it possible to complete it in 60 days.

Made by the Artistic Metal Works, San Francisco from a half-size clay model produced by Olof Malmquist, sculptor, and gold leafed by J. H. Mohr, Inc., the Phoenix was assembled around an 8-inch H-column from top to bottom, with a cobweb of reinforcing braces. It was then cut into 5 sections, moved to Treasure Island, and rewelded around a duplicate H-beam which was later imbedded 19 feet into the top of the Tower of the Sun. From this pinnacle, 400 feet in the air (see illustration below) facing the Golden Gate, the Phoenix will glisten by day and by night during the 1939 Western World's Fair.



Courtesy Lincoln Electric Co.

A. S. M. E. NOMINATIONS

Nominations for Officers of The American Society of Mechanical Engineers for 1939 were announced at a recent meeting of the Nominating Committee held at St. Louis, Mo., during the Semi-Annual Meeting. Election will be held by letter ballot of the entire membership closing on September 27, 1938.

The nominees as presented by the Regular Nominating Committee of the Society are:

President (To serve 1 year)—Alexander G. Christie, Professor of Mechanical Engineering, Johns Hopkins University, Baltimore, Md.

Vice-Presidents (To serve 1 year)—Henry H. Snelling, Senior Member, Snelling & Hendricks, Washington, D. C.

(To serve 2 years)—W. Lyle Dudley, Vice-President, Charge of Design & Sales, Western Blower Company, Seattle, Wash.

James W. Parker, Vice-President and Chief Engineer, Detroit Edison Company, Detroit, Mich.

Alfred Iddles, Application Engineer, Babcock & Wilcox Company, New York, N. Y.

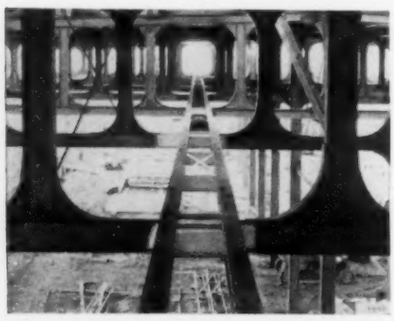
Managers (To serve 3 years)—Clarke Freeman, Vice-President, Charge Fire Prevention Engrg. & Underwriting, Mfrs. Mutual Fire Ins. Company, Providence, R. I.

Willis R. Woolrich, Dean of Engineering, University of Texas, Austin, Texas.

William H. Winterrowd, Vice-Chairman, Franklin Railway Supply Company, Chicago, Ill.

FERTILIZER PLANT

The new fertilizer plant for International Agricultural Corp., first industrial structure utilizing the new welded portal truss designed by engineers of The Austin Co. to accommodate conveyors on rails passing through the roof members, is nearing completion at Chicago Heights, Ill.



Industrial Cars Will Soon Be Operating Through These Portals in the Welded Rigid Frame Fertilizer Plant Which The Austin Company is erecting at Chicago Heights, Ill., for International Agricultural Corp. Rails Will Be Bolted to the Conveyor Supports Which Extend Between the Trusses and Cars Operating on Them Will Be Loaded from Belt Conveyors Overhead. Tracks Have Been Installed Through Four of the Twelve 7-Ft. Portals in These Trusses

The unusual trusses, which are a functional part of this all-welded rigid-frame structure, were completely prefabricated in the Austin shops at Cleveland. They provide twelve 7-ft. passageways just below the building's roof and rails extending between the trusses will carry industrial cars, which in turn will be loaded from elevator towers overhead. Special rail supports, as well as all the other structural members, were welded in the Cleveland fabricating shop. A total of 250 tons of structural steel was used on the job, which required 13,000 lineal feet of welding, only 1100 feet of which were welded in the field.

The design lends itself to many other uses, since the portal trusses will accommodate monorails directly on their bottom chords and will provide conveyorways or walkways through the portals, as well.

SURFACE HARDENING

One of the highlights at the Welding Clinic recently held at the La Crosse Vocational School in La Crosse, Wisconsin, was W. V. Emery's discussion on "Surface Hardening of Welded Units." Mr. Emery, Welding Foreman in the huge shops of the Harnischfeger Corporation of Wisconsin is well qualified to give a thoroughly informative and interesting résumé of this subject. He is a popular speaker among branches of the AMERICAN WELDING SOCIETY and similar groups, anxious to amplify theoretical knowledge with the practical, tried and proved methods and theories developed by men engaged in the design and production end of the welding industry.

MOTION PICTURE ON PLOWSHARE HARD-FACING

The use of hard-facing as an economical method of increasing the life of plowshares is depicted in the motion picture, "Haynes Stelliting the Plowshare," which is available for showings from the offices of either The Linde Air Products Company or Haynes Stellite Company. This film will be of interest to farmers, welding shop owners, ironsmiths, and all others concerned with the maintenance of agricultural implements. Its thorough treatment of the many advantages and economies of hard-facing should make it a valuable aid in building up sales.

A clear, step-by-step presentation of every detail of cleaning, grinding, hard-facing and subsequent sharpening operations is given. In addition, several interesting views show the use of a copper nose plate for quickly forming the hard-facing alloy on the nose of the share. Side and bottom suction, and the methods used to retain them after hard-facing, are also included in this instructive film.

245-TON, 92-FOOT BUBBLE TOWER SHIPPED NEARLY A THOUSAND MILES BY RAIL

The largest single piece of industrial equipment ever made in St. Louis—a steel tower 92 feet long, weighing 245 tons—has been completed at the Heine Boiler Division of the Combustion Engineering Company, Inc., and has completed its 916-mile journey overland to Smith's Bluff, Texas, where it will be used in the Pure Oil Company refinery.

Equal in weight to about 170 popular priced automobiles which shipped assembled would require 34 freight cars, the tower was one of the heaviest and largest single pieces of freight ever shipped by rail. Special equipment in the form of 400,000-pound capacity freight cars with 16 wheels each was used to carry the load. There are only four such cars in use in the United States. Shipments were handled by the Frisco Railway to Neosho, Mo., and from there by the Kansas City Southern Railway direct to the refinery.

SIX NEW BLAST FURNACE STOVES ARE FIRST OF TYPE ERECTED

Shown on the left of the accompanying illustration are three all-welded blast furnace stoves erected by the Pittsburgh-Des Moines Steel Company, Neville Island, Pennsylvania for a Pennsylvania steel mill.

The stoves are 24 feet in diameter and 104 feet high. They are constructed of $^{3}/_{4}$-inch and $^{5}/_{8}$-inch steel plate all butt welded and tested to 45-lb. pressure as required by the specifications. The use of welding in construction is reported to have saved 30% in weight and approximately 50% in time of erection.

Also illustrated (at right) are three additional stoves erected for the same steel mill. These are 24 feet in diameter and 104-feet high. They were fabricated and erected by the Chicago Bridge & Iron Company, Chicago, Illinois.

The welding in construction of these blast furnace stoves was all done with shielded-arc equipment.

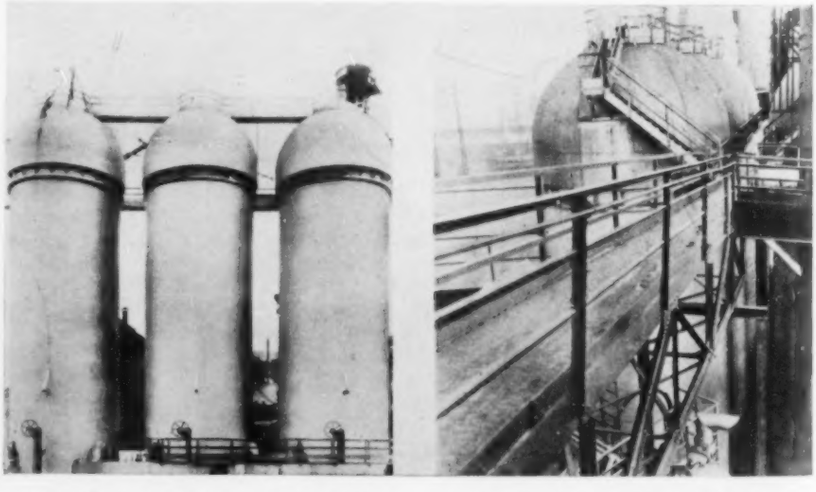


Photo courtesy of The Lincoln Electric Company, Cleveland, Ohio.

Six All-Welded Blast Furnace Stoves, Erected at a Steel Mill in Pennsylvania, Believed First of the Type Ever Built in This Country. (Left)—3 Stoves Erected by Pittsburgh-Des Moines Steel Company of Neville Island, Pa. (Right)—3 Stoves Erected by Chicago Bridge & Iron Company, Chicago, Illinois

» » » SECTION ACTIVITIES « « «

CINCINNATI

At the Annual Meeting of the Cincinnati Section held on June 22nd, the following Officers and members of Executive Committee were elected.

Chairman—F. H. Smith, The Lincoln Electric Co.

Vice-Chairman—Clayton D. Breese, The Breese Bros. Co.

Treasurer—James K. Ross, The United Welding Co.

Secretary—Eric O'Hara, The Cincinnati Gas & Elec. Co.

Executive Committee—Term 2 years: D. C. Gardner, Gardner Publications, Inc., W. W. Petry, Cincinnati Milling Machine Co. and W. P. Dettwiler, Williams & Co.

Executive Committee—Term 1 year: W. A. Maddox, Cincinnati Milling Machine Co., C. H. Hittle, Oregonia Bridge Co. and O. A. Tilton, General Electric Co.

At the first meeting of the Executive Committee, held July 13th, next year's program was tentatively outlined, and decision was made to actively affiliate with the Cincinnati Engineers' Club and join the Engineering Council.

CLEVELAND

The newly elected Officers and Committee Chairmen of the Cleveland Section are:

Chairman—Prof. Fred L. Plummer, Case School of Applied Science

Vice-Chairman—Ed. T. Scott, Pres., Cleveland School of Welding

Secretary-Treas.—A. L. Pfeil, Universal Power Corp.

Membership Chairman—L. H. Frost

Executive Committee—Fred L. Plummer

Papers Committee—G. T. Williams

Educational Committee—A. E. Gibson

Publicity Committee—C. T. Elder

Code Committee—A. S. Low

Nominating Committee—E. R. Benedict

The Section has plans completed for an educational lecture course starting in the fall to be conducted by Mr. John H. Kincaid, Chief Engineer of Design for Wellman Engineering Company, which will instruct designing engineers and welding men in the shop in the proper marking and interpretation of drawings of welding parts. This course will include the new system of symbols for making welding drawings devised by the A. W. S.

KANSAS CITY

The June meeting of the Kansas City Section was held on Monday night, June 27, 1938. Moving pictures of the passenger and freight car construction were shown by the courtesy of the Pullman Standard Car Manufacturing Company. This was the last meeting before the summer vacation period. The next regular monthly meeting will be held in September and will be a dinner meeting.

The Past-President and first Chairman of the Kansas City Section (C. E. Woodman) presented a beautiful gavel to the present Chairman (C. A. Hall.) Mr. Woodman, himself, made this gavel out of an old baseball bat which had been discarded by one of his children. After hearing so much talk about salvaging and reclaiming worn and broken pieces of metal, he decided that this might be carried over into the wood-working field.

MARYLAND

At an Executive Committee meeting held June 13th, Vice-Chairman Leo Gould was appointed as a committee of one to provide speaker for Section meetings. It was voted that oyster roast be continued as an annual affair Messrs. Harry Ross, Chairman, John Cumberland and Dr. Miller were appointed committee in charge. It is planned to hold Section meetings third Friday of month, beginning November 1938. It is planned to get nationally known speakers for the season's meetings. Dr. J. W. Miller was appointed Chairman of Membership Committee.

NEW YORK

At an Executive Committee meeting of the New York Section held July 5th, after considerable discussion, a motion was passed to continue the Lecture Course.

The following committees were appointed by the Chairman:

Lecture Course Committee—S. S. Scott, Chairman, W. Spraragen, Editor A. W. S. Journal, Dr. Claussen, Dr. Henry, E. Vom Steeg, Wayne Howard, E. V. David and Charles Kandel

Membership Committee—Charles Kandel, Chairman

Program Committee—E. V. David, Chairman, G. D. Fish, J. T. Phillips, C. W. Bryan, Jr. and S. S. Scott

Entertainment Committee—Charles Kandel, Chairman, A. F. Keogh and Wayne Howard

By-Laws Committee—E. Vom Steeg, Chairman

NORTHWEST

Because the meetings of the members are suspended during the summer months, and because vacations are responsible for many being out of town, Section activities are at the low point of the year.

The Executive Committee of the Section had the pleasure of entertaining Dr. G. E. Claussen, Research Assistant, Welding Research Committee of the Engineering Foundation, at luncheon upon his recent visit to Minneapolis, when he came to confer with the members of the faculty of the University of Minnesota in regard to stimulating interest in research work in welding. T. P. Hughes, assistant professor of mechanical engineering at the University, and a member of the Executive Committee of the Section, made it possible for Dr. Claussen to meet a number of the faculty of the University. At the luncheon Dr. Claussen gave a very interesting review of the work of the Engineering Foundation, and what it had accomplished.

OKLAHOMA CITY

The regular monthly meeting of the Oklahoma City Section has been discontinued through the summer months. However, the officers and committeemen are active in preparing a program for the 1938-39 season.

A meeting of the Executive Committee was held June 21st, at which time many items of importance in connection with the establishment of these programs were discussed, and with a very good attendance.

The Meetings and Programs committee is under the leadership of C. C. Willis, and definite steps have been taken toward securing speakers for meetings next fall and winter.

Charles Bowen, as Chairman of the Educational and Lecture Course Committee, has been very active with his committee in securing material and outlines which will lead to a lecture series and educational programs of much value.

The work of the Membership committee is under the leadership of M. F. Dunne and with the support of his committeemen and the present membership, a steady growth of the Oklahoma City Section can be expected.

SAN JOAQUIN

The closing meeting for the 1937-38 season was held on June 9th. Old business was disposed of and new Officers for the ensuing year were installed. Short talks were made by several members expressing their desire for a renewed effort to obtain a larger membership. Appreciation was expressed by members to the Officers and Committees for their work during the first year of the Section.

The following are the Officers and Chairmen of Committees appointed:

Chairman—J. W. Steen, Standard Oil Co.

Vice-Chairman—G. D. Atmore, Air Reduction Sales Co.

Secretary—H. S. Nix, Taft Union High School

Treasurer—I. K. Vandam, Kern County Union High School

Executive Committee Chairman—E. R. Harrison

Membership Committee Chairman—J. M. Bridges

Program Committee Chairman—H. Hammett

Entertainment & Publicity Committee—S. L. Howard

Educational & Library Committee—H. Hammett

ST. LOUIS

Mr. A. R. Ross has been elected Secretary of the St. Louis Section for 1938-39.

Mr. Ross is Associate to the President of the Board of Public Service, City of St. Louis.

Mr. R. C. Thumser, Chairman of the Meetings Committee, reports that the programs for September 1938 to May 1939 have been practically completed.

It was decided to strengthen the program of the section for the coming year. The following Meetings were proposed:

SEPTEMBER 27, 1938: Possible joint meeting with the American Society of Mechanical Engineers. Subject to be the "Waterside Station of the Consolidated Edison Company" which would feature heavy pressure piping.

NOVEMBER 8, 1938: "Structural Steel Welding" to feature recent construction in and around New York City. It was proposed to have Mr. Fish head this meeting. It was also thought possible to feature a short talk on "Codes" in connection with this meeting.

DECEMBER 13, 1938: "Re-design in Machine Construction." As speakers, it was suggested we have either Mr. Isgren of Letourneau Corporation or Mr. Chapman of the Lukens Steel Company.

JANUARY 10, 1939: "Explosion and Impact Tests" by Leon C. Bibber of Carnegie Illinois Steel Company.

FEBRUARY 7, 1939: "Non-Ferrous Metals."

MARCH 8, 1939: "Shipbuilding."

APRIL 11, 1939: "Low Alloy Steels" with a half hour talk by a representative of the Worlds Fair, as a preliminary to the proposed May meeting at the Fair Ground.

MAY 9, 1939: Business meeting and Dinner at the Fair Grounds. It was decided to invite neighboring Sections and to endeavor to have an AMERICAN WELDING SOCIETY Day at the Fair.

All meetings, except the May 10th meeting, are to be held at the Engineering Societies Building. It was decided to start at 7:30 instead of 8:00 o'clock.

To strengthen the program, it was also decided to have only one speaker and to prepare a number of pre-arranged short discussions of the papers to stimulate discussions from the floor.

Mr. Kandel was delegated to investigate the cost of a dinner at the Fair, the price to be in the neighborhood of $5.00 per couple.

It was decided to attempt to have some inspection trips. Mr. Kandel is to endeavor to arrange an inspection trip to the new all-welded telephone building early in August and $25 was temporarily set aside to cover the cost of refreshments.

TULSA

The last Summer Meeting of the Tulsa Section was held on June, 24th. The speakers of the evening were: Orville T. Barnett, Metallurgist, Black, Sivalls & Bryson, Inc., and W. Mike Murphy, Engineer to the Petroleum Industry, Air Reduction Sales Company. Their subjects were: "The effect of welding heat on mild steel plate" and "Development of the welding of oil well casing."

WASHINGTON, D. C.

The following Officers for the ensuing year have been elected by the Washington Section.

Chairman—C. M. Underwood
Vice-Chairman—C. A. Loomis
Secretary—N. W. Morgan
Treasurer—R. F. Wood
Executive Committee—2 years: A. G. Bissell, G. E. Knox, E. R. Patton, R. B. Swope, C. E. Meissner and T. W. Wilson
Executive Committee—1 year: W. F. Dietz, W. S. Farr, R. P. McMillan, G. F. Jenks, G. A. Ellinger and R. J. Meybin

WESTERN NEW YORK

The Western New York Section reports the following Officers elected for the coming year:

Chairman—J. R. Dawson
Vice-Chairman—Robert Siemer
Secretary—C. S. Freeman
Treasurer—F. O. Howard

WICHITA

There was an attendance of about 85 men at the June 30th meeting of the Wichita Section. Mr. M. F. Dunne, District Supervisor of the Air Reduction Sales Company, presented a paper on "Low Temperature Brazing," which he illustrated with slides. After the meeting a practical demonstration was given along the lines of the speaker's subject.

YOUNGSTOWN

On May 16th the Youngstown Section had their Annual Meeting and election of officers as follows:

Chairman—A. O. Miller, Petroleum Iron Works
Vice-Chairman—Grover Hughes, Truscon Steel Co.
Secretary-Treasurer—J. J. Moriarty, The Linde Air Products Co.

Films on The Making of Steel from the Mine to the Finished Strip were shown through the courtesy of the Youngstown Sheet & Tube Company.

IMPORTANT NOTICE

Effective July 30th the Executive Committee of the AMERICAN WELDING SOCIETY has done away with the office of the Managing Director and dispensed with the services of the present incumbent. A Committee has been appointed to draw up plans and programs for the increase of the Society activities along technical lines. A report will be rendered at a later date.

HOBART CATALOG

The new "Multi-Range" catalog of the Hobart Brothers—Hobart Square, Troy, Ohio telling of their improvements in Arc Welding is now available.

INTERNATIONAL ACETYLENE CONGRESS

The thirteenth International Acetylene Congress is scheduled for June 25-July 1, 1939 at Munich, Germany. There will be 13 different sessions as well an international acetylene exposition.

STEEL FOUNDERS' SOCIETY APPOINTS C. W. BRIGGS TECHNICAL ENGINEER

Steel Founders' Society of America, Cleveland, Ohio, is pleased to announce that on or about October 1, 1938, Mr. C. W. Briggs, Physical Metallurgist, Naval Research Laboratory, Washington, D. C., will join the Society's Staff in the capacity of Technical Engineer. Mr. Briggs is a graduate of Stanford University. Since taking his degree in Metallurgy (Sigma Xi) he has devoted most of his time to research work for the U. S. Navy, being at present the directing head of the Steel Casting research department. Most of his investigations have had to do with Steel Casting development work.

Among the projects which Mr. Briggs will initiate in his new connection will be the development of a Cast Steel Data Book for the use of engineers, designers, engineering students, etc. He will likewise handle other technical phases of the Society's activities.

MUREX RODS

Metal & Thermit Corporation, 120 Broadway, New York, announces a new edition of its handy, pocket-size pamphlet on Murex welding rods.

Considerably revised and enlarged, the new issue contains brief data on the physical properties and chemical analysis of the weld-metal deposited by each of the twenty odd electrodes in the Murex line. Included are individual, specially designed electrodes for high speed, downhand welding of mild steel; for all-position welding; for horizontal fillet work; for welding manganese, carbon-molybdenum and nickel steels; for several types of stainless steels; and, for a number of the new high-strength, low-alloy steels.

THERMIT WELDING

A new thirty-four page booklet describing the Thermit Welding process and its applications is announced by the Metal & Thermit Corporation, 120 Broadway, New York.

Far more complete than anything published previously on the subject, the new booklet gives the history of Thermit Welding; describes the nature of the Thermit reaction, by means of which superheated liquid steel is produced for welding purposes; discusses the physical properties of Thermit weld-metal; outlines the methods employed in welding. In addition, the advantages and economies of the process, for emergency repairs in the marine field; for repairs throughout industry to machine frames, crankshafts and other heavy parts; for reclamation work in steel mills; and for rail welding on steam railroad, street railway and coal mine track, are thoroughly covered. Also, several pages are devoted to Thermit for foundry use, and to the pure, carbide-free metals and alloys produced by the Thermit reaction and used for alloying purposes in

the manufacture of steel and non-ferrous alloys.

GAS CUTTING PAMPHLET

A very attractive bulletin has been issued by the Victor Equipment Company, 844 Folsom Street, San Francisco, Calif., containing information on fuel gases, actions taking place in cutting, cutting speeds, information on technique and repair and a list of torches available by this company.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-277. Class B welder capable of oil tight jobs; can do overhead welding and handle most wires. Have worked for the General Electric Company.

A-278. 1st class welder with three years' experience in shipyard welding; passed all Government tests, including stainless steel welding. Willing to travel.

A-279. Arc welder with three years' experience in vertical and overhead work. Experienced in Fleetweld, hard weld, Ferroweld, structural frame work, pipe line outside, steel mill and job shop work. Also worked in garage doing repair welding. Passed Navy test in welding.

A-280. Electric welder with ten years' experience.

A-281. Expert Welding Engineer. Good salesman with wide experience in export, with previous practice in Crane design and Steelworks layout, wants position in U. S. A.

OBITUARY

LONIE E. COBB

Mr. Lonie E. Cobb died on May 25, 1938. Mr. Cobb was a member of the Birmingham Section of the AMERICAN WELDING SOCIETY. He was connected with such companies as the Standard Steel Car Company, The Graver Tank Works. He then became Superintendent of the Fabricating Dept., Goslin Birmingham Manufacturing Company. Mr. Cobb was active in all affairs of the Birmingham Chapter of the AMERICAN WELDING SOCIETY, and at the time of his death was Vice-Chairman of the Local Chapter. He was a man of unusual ability, and good personality.

HERBERT C. JENNISON

Mr. Herbert C. Jennison, Technical Manager of The American Brass Company, died after a short illness June 12th at his home, Brooklawn Park Hills, Bridgeport, Connecticut.

Mr. Jennison has been connected with The American Brass Company since 1900—first as Laboratory Assistant, then as Testing Engineer. From 1919 to 1923 he was Technical Supervisor of the Ansonia Branch of The American Brass Company and in 1923 came to Waterbury as Technical Superintendent. In 1934 Mr. Jennison was appointed Technical Manager, which position he held at the time of his death.

Mr. Jennison's early education was obtained in the schools of Bridgeport, Connecticut, this being supplemented by active outside studies. As a part of his activities with The American Brass Company he was concerned with the work of numerous technical committees of National Engineering Societies, particularly those in the Non-Ferrous field, such as Copper and Copper Alloy Wires and Non-Ferrous Metals and Alloys for the American Society for Testing Materials. He was also a member of the Joint Committee on Trolley Wire Specifications and was a member of the Non-Ferrous Metals Division of the Society of Automotive Engineers.

Mr. Jennison was a member of the Metallurgical Advisory Board of the Army Ordnance Department and the Metallurgical Advisory Board of the U. S. Bureau of Standards, Washington, D. C. He held membership in the American Society for Testing Materials, American Institute of Mining & Metallurgical Engineers, British Institute of Metals, American Institute of Electrical Engineers and the Electro Chemical Society.

Mr. Jennison is survived by a sister, Miss Helen E. Jennison of Bridgeport, Connecticut.

The funeral was held Friday, June 17th at 2:30 P.M. from the home, with interment in Framingham, Massachusetts.

List of New Members

June 1 to June 30, 1938

BOSTON

Adams, Ernest N. (C), 192 Chandler St., Worcester, Mass.
Davis, F. W. (A), E. B. Badger & Sons, 75 Pitts St., Boston, Mass.

CHICAGO

Bradley, Chas. E. (D), 2537 E. 75th St., Chicago, Ill.
Penn, Henry (C), American Inst. of Steel Const., 53 W. Jackson Blvd., Chicago, Ill.
Schiemann, E. H. (C), Public Utility Bag & Serv. Corp., 231 S. La Salle St., Chicago, Ill.

CLEVELAND

Hudson, D. D. (D), 14012 Lake Shore Blvd., Cleveland, Ohio.
Miller, Alexander (C), American Inst. of Steel Const., 2120 N. B. C. Bldg., Cleveland, Ohio.

COLUMBUS

Mitchell, Arthur J. (B), 720 Thomas Ave., Columbus, Ohio.

DENVER

Organ, C. J. (D), Box No. 42, Denver Sta., Denver, Colo.

DETROIT

Dow, William G. (B), 1417 Golden Ave., Ann Arbor, Mich.
Taylor, E. W. (B), 135 Washington St., Bay City, Mich.

GEORGIA

Bloxton, C. R. (C), 405 Bona-Allan Bldg., Atlanta, Ga.

HAWAII

Elliott, William (B), 2617 Ala Wai Blvd., Honolulu, T. H.

KANSAS CITY

Singleton, Jack, (C), 622 New England Bldg., Topeka, Kansas.

LOS ANGELES

Bringer, R. A. (D), 2252 Ewing St., Los Angeles, Calif.
Ley, Harry J. (C), San Pedro High School, Alma & 15th Sts., San Pedro, Calif.
Mangrum, R. L. (B), Mangrum & Page, 5703 Cherry Ave., Long Beach, Calif.
McGinnis, C. E. (B), Board of Mech. Engrs., Room M-85, City Hall, Los Angeles, Calif.
Rokes, D. G. (D), 6245 Walker Ave., Bell, Calif.

MILWAUKEE

Barrett, R. C. (B), 732 First National Bank Bldg., Milwaukee, Wisc.
Reichert, Harold W. (C), 2629 W. Cherry St., Milwaukee, Wisc.

MONTANA

Fradet, John D. (C), Great Northern Tool & Supply Co., Box 957, Billings, Mont.
Runnion, Marion C. (D), 920 6th Ave., S., Glasgow, Mont.
Strissel, Daniel (D), Box 546, Fort Peck, Mont.

NEW YORK

Emery, Willard A. (A), Worthington Pump & Mach. Corp., Harrison Works, Harrison, N. J.
Evans, W. L. (D), Foster Wheeler Corp., Carteret, N. J.
Kerbey, E. A. (C), Midwest Piping & Supply Co., 30 Church St., New York, N. Y.
Lonsdale, W. (B), Foster Wheeler Corp., Carteret, N. J.
Magrath, J. G. (C), Air Reduction Sales Co., 60 E. 42nd St., New York, N. Y.

Osborne, T. W. (D), 10 Bennett Ave., New York, N. Y.
Price, P. L. (C), American Inst. of Steel Const., 200 Madison Ave., New York, N. Y.
Wilson, J. Lyell (C), American Bureau of Shipping, 24 Old Slip, New York, N. Y.

NORTHERN NEW YORK

Ramer, E. J. (C), 41 Barrows St., Albany, N. Y.

NORTHWEST

Caswell, Alexis (C), Mfrs. Assoc. of Minn., Inc., 405 Marquette Ave., Minneapolis, Minn.

OKLAHOMA CITY

Miller, C. P. (D), Box H 47, Seminole, Okla.

PEORIA

Arthur, Guy (B), 908 E. Arcadia St., Peoria, Illinois.
Brooking, Walter J. (B), R. G. Le Tourneau, Inc., Ft. of Grant St., Peoria, Ill.
Cochran, Virgil (B), 230 Grant St., Peoria, Ill.
Dubie, O. L. (C), R. G. Le Tourneau, Inc., Grant St., Peoria, Ill.
Farris, Howard S. (C), 100 N. 13th St., Pekin, Ill.
Filker, Arthur G. (C), 334 N. West St., Farmington, Ill.
Hanley, John (B), A. Lucas & Sons, Peoria, Ill.
Hanson, Vernon E. (C), 318 W. Lake, Peoria Hts., Ill.
Hardbarger, Lyle H. (C), 1702 N. Madison St., Peoria, Ill.
Isgren, Elmer (A), R. G. Le Tourneau, Inc., Peoria, Ill.
Lohnes, Stearn (C), A. Lucas & Sons, Peoria, Ill.
Matheny, Thos. (C), 1516 First St., Pekin, Ill.
Miller, Elmer L. (C), R. G. Le Tourneau, Inc., Ft. of Grant St., Peoria, Ill.
Reist, J. F. (B), 318 Seibold St., Peoria, Ill.
Roberts, G. R. (C), National Cylinder Gas Co., Ft. of E. Franklin St., Peoria, Ill.
Runkel, R. W. (C), 1900 N. Jefferson, Peoria, Ill.
Rutledge, Robert (C), A. Lucas & Sons, Peoria, Ill.
Salvador, J. V. (C), 924 Hamilton Blvd., Peoria, Ill.
Schmidt, E. C. (C), 706 W. Corrington Ave., Peoria, Ill.
Sivley, G. A. (C), 2226 Missouri Ave., Peoria, Ill.
Van Dyke, E. E. (C), R. R. 5, Peoria, Ill.
Wegner, Russell (C), 525 McBean St., Peoria, Ill.
Wilson, R. A. (B), 922 Hamilton Blvd., Peoria, Ill.
Wimmer, Clifford (C), 110 Franklin St., Bartonville, Ill.

PHILADELPHIA

Cleeland, Robert (C), Rubicon Co., 29 N. 6th Place, Philadelphia, Pa.
Gibson, W. Herbert (C), 2110 Architects Bldg., Philadelphia, Pa.
Hastings, B. F. (C), 1737 Chestnut St., Room 308, Philadelphia, Pa.
Shoyock, Joseph G. (B), c/o Belmont Iron Wks., 22nd St. & Washington Ave., Philadelphia, Pa.

ROCHESTER

Mather, William (D), 32 Strohm St., Rochester, N. Y.
O'Neil, Edgar (B), 11 Argyle St., Rochester, N. Y.
Wilson, G. G. (C), 224 Scholfield Road, Rochester, N. Y.

ST. LOUIS

Dodd, L. H. (C), 1405 Paul Brown Bldg., St. Louis, Mo.
Wehmeyer, C. W. (C), Combustion Engrg. Co., 5319 Shreve Ave., St. Louis, Mo.

SAN FRANCISCO

Leonhauser, A. O. (C), 437 A. Tehama St., San Francisco, Calif.
Emmett, W. E. (C), 303 Sharon Bldg., San Francisco, Calif.

SOUTH TEXAS

Surguy, H. L. (D), 6847 Avenue F, Houston, Texas.
Westmoreland, W. L. (C), Champion Paper & Fibre Co., Pasadena, Texas.

TULSA

Briggs, Clay (C), Cities Service Oil Co., Bartlesville, Okla.
Grubbs, Vernon (D), 1016½ N. Delaware, Tulsa, Okla.
McLaughlin, W. A. (D), R. 6, Box 381, Tulsa, Okla.
Meyers, Phil (D), 1143 E. Third St., Cushing, Okla.
Reed, Harley M. (D), Mid-Continent Pet. Corp., 1406 W. Admiral, Tulsa, Okla.
Stoops, F. D. (D), 1623 W. 18th St., Tulsa, Okla.
Wilson, Loy (B), O. C. Whitaker, P. O. Box 2619, Tulsa, Okla.
Wright, H. H. (B), P. O. Box 661, Tulsa, Okla.

WICHITA

Ellison, Ralph (D), 710 E. First, Wichita, Kansas.
Swenson, D. A. (B), Western Iron & Foundry. Co., 702 E. 2nd St., Wichita, Kansas.

NOT IN SECTIONS

Abaunza, A. E. (C), 1031 Annunciation St., New Orleans, La.
Bell, Mace H. (C), 506 Stern Bldg., New Orleans, La.
Forssell, Pontus (C), Eriksbergs Mek., Verkstadsaktiebolag, Gothenburg, Sweden.
Higgins, E. C. (B), 1755 St. Charles Ave., New Orleans, La.
Howell, A. J. (D), 844 Franklin S. E., Grand Rapids, Mich.
Huet, G. O. (B), 1755 St. Charles Ave., New Orleans, La.
Pine, Clyde (B), 615 City Park Ave., New Orleans, La.
Pingree, C. C. (B), Whitmore Oxygen Co., 430 E. So. Temple St., Salt Lake City, Utah.
Purvis, Henry R. (D), North Carolina Pulp Co., Fort Williams St., Plymouth, N. C.

Sustaining Companies

Churchward Engineering Co., Inc., 33 Sperry St., New Haven, Conn. Manufacturer of the Duro line of completely insulated and non-insulated electrode holders for use in electric arc welding. Insulated types have metal parts completely protected from accidental arcing of the holder. Available in three sizes, Standard, Junior and Senior covering a range of 1/16-inch to 3/8-inch electrodes and ranging in weight from 9 ounces to 32 ounces. Features claimed are easily replaceable parts, extreme lightness, coolness and perfect balance, as well as rugged construction and extreme precision of manufacture.

E. B. Badger & Sons Co., 75 Pitts St., Boston, Mass. Established 1841. Designers and builders of complete plants and equipment for distillation and treating of petroleum oils. Complete laboratory for evaluation of crudes and petroleum products. Designers and builders of complete chemical plants for the production of alcohol, solvents, synthetic chemicals, coal tar products, cellulose products, paints, etc.; for the rubber, food product and soap industries, etc., and recovery of wastes. Corrugated expansion joints for steam, oil and process piping, including high temperatures and pressures.

The National Tank Company, Tulsa Okla., specializes in steel plate products fabricated by electric welding. These products include tanks and other vessels for various purposes, with specialization given to tanks for the oil industry. Of the principal items of manufacture, oil and gas separators constitute the majority. These vessels have been made by electric welding for cold working pressures as high as 3500 pounds. Vessels are made to A. S. M. E. and A. P. I.-A. S. M. E. specifications and plant facilities include stress relieving oven, tensile testing machine and other equipment for proper construction of welded vessels.

The Worthington Pump and Machinery Corporation, Harrison, N. J., builds all kinds and sizes of Air and Gas Compressors, Vertical and Horizontal; Air Conditioning and Refrigerating Equipment; Surface Condensers and Feed Water Heaters with either welded steel shells, or cast, as required. Steam, Diesel and Gas Engines, Steam Turbines. Reciprocating and centrifugal pumping machinery—all sorts and sizes for every kind of service. Rock Drills and Contractors Tools. Liquid Meters; V-Belt Drives.

Wheeling Steel Corporation, General Offices, Wheeling, W. Va. Manufacturers of Hot and Cold Rolled Sheets, Galvanized Sheets, Black and Galvanized Merchant Pipe, Line Pipe, Casing and Tubing; pipe for special uses including Wheeling COP-R-LOY Pipe and Wheeling Open-Hearth Ammonia Pipe; Tin Plate, Terne Plate and Black Plate, including DUCTILLITE; Rods and Wire, including WELDING RODS, Wire and Wire Products, Wire Nails, Cut Nails; galvanized Range Boilers, Heater Tanks and Steel Barrels.

NEW PRODUCTS

The Society assumes no responsibility for the validity of claims in this Section

PREVENTING ADHERING WELD SPATTER

A new material (Glyptal No. 1294) has been announced by General Electric for the prevention of the adhesion of weld spatter to metals which are to be welded. This material, which can be used without harm on any metal surface, including polished stainless steel, will not produce carbon to make the weld hard or brittle, nor will it reduce ductility. Likewise, it will not give off smoke to fog up the atmosphere and it will not form gas pockets or cause the weld to be porous.

In applying the new Glyptal preparation, spraying is preferred to brushing because the former method assures a thinner coat. A thin coating will protect the work as well as a thick coating, if the surface is completely covered, is more economical, and dries faster. On surfaces which are to be painted, this material further serves as an excellent priming coat. In addition, it prevents the forming of rust on steel in storage yards. This is particularly important if the steel is to be subsequently welded.

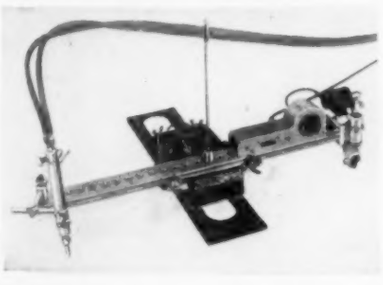
A. C. ARC WELDER

A new alternating current welding machine is being announced and placed on the market by the Owen-Dyneto Corp. of Syracuse, N. Y., it being marketed under the trade name "USL Protected Arc AC Welder."

Features of the new A.C. machine insure high efficiency and wide range of applications. It is designed to connect to any standard voltage or frequency power line. It is rated at 150 amperes and has a range from 30 amperes to 280 amperes output. Open circuit voltage of 55 volts maintaining 20 volts to 30 volts across the arc. USL Engineers state that the new unit was designed to fill the demand for a quality alternating welder that would meet the most grueling service requirements over a long period of life and still be within the range of popular price.

AUTOMATIC GAS-O-GRAPH

This automatic mechanical flame cutting machine for all types of shapes from plates and billets is manufactured by Compressed Industrial Gases, Inc., 221 N. LaSalle Street, Chicago, Ill. Within a range of thirty inches in width and unlimited length, this new machine as illustrated can cut any type of shape. Machines to cut wider than thirty inches in width can be made to special order. Cuts made by the Automatic Gas-O-Graph are so clean and so accurate that machining is seldom required. Cutting can be done from a tracing, template or pattern, and more than one torch can be used when multiple cuts are desired.



NEW ELECTRODE—FOR WELDING TOOL STEEL

The Harnischfeger Corporation of Milwaukee announces another in their long line of Smootharc welding electrodes—Smootharc "Hartung." With a base metal of the highest quality tungsten molybdenum wire, this electrode is used for making tool steel cutting edges on medium carbon steel or for rebuilding worn tools and dies. The analysis of its deposited metal is equal in composition and in property to the highest grade of high speed tool steels on the marekt: yet it has extreme air hardening properties which, without treatment, possess hardness values in excess of 60 Rockwell "C."

NEW AIR HAMMER AND ARC WELDER

Borm Manufacturing Co., Elgin, Illinois have just developed and are offering to distributors and users a new Elgin low priced A. C. Arc Welder with six graduated heat taps—20 to 120 amp. Good for continuous welding on 110 volts and intermittent on 220 volts, using up to $^1/_8$ inch A. C. Standard Coated Welding Rods.

They have also added to their hammer line the compact efficient simple construction model illustrated—so convenient it can hang on the operator's belt like any other tool. Embodies their larger model tool holder and other exclusive features of the Elgin air hammers.

REGULATOR FOR REDUCING AND STABILIZING AIR PRESSURES

This new and different "Midget" Regulator is made possible by the patented Dockson process of die casting alloys into finished regulator parts.

Precision and savings in manufacture, never previously obtained by other methods, now revolutionize the apparatus for control of air pressures through the reduction and stabilization of these pressures.

Dockson Engineers will make suggestions for the solution of particular problems.

C. H. Dockson Company, 2885 East Grand Boulevard, Detroit, Michigan.

COMPOUND FACILITATES CLEANING AFTER WELDING

A new compound, which is said to reduce cleaning time after welding by 20 to 60%, is announced by The Lincoln Electric Company, Cleveland, Ohio.

This new compound, known as "Spatter Film," has been developed by Lincoln engineers to increase the economy of electric welding as a process of manufacture and fabrication. By reducing the tendency of spatter to adhere tightly, thus facilitating its removal, "Spatter Film" makes fabrication by arc welding still more economical. The savings resulting from use of the compound will be particularly apparent in work where painting and finishing are essential.

"Spatter Film" is soluble in water. It is non-inflammable and contains no free alkali to injure the hands nor harm paint. It is easy to apply by means of an ordinary paint brush. Only sufficient of the film need be applied to cover the work adjacent to the seam or joint. A gallon of "Spatter Film" will cover appropriately 50,000 sq. inches of surface. It can be removed readily for painting by wiping with a clean cloth, if still wet, or by washing it off with water if dry.

INEXPENSIVE IGNITRON WELDING TIMERS

Continued improvements of ignitron tubes and simplified circuits and construction has resulted in an inexpensive Westinghouse ignitron spot-welding timer, Type SP-11. This timer will mount two sizes of ignitron tubes. On low duty cycles, the WL-652 tube will carry 1500 amperes at 220, 440 or 550 volts, while the WL-651 will carry 2800 amperes at 440 and 550 volts or 4300 amperes at 220 volts. The current rating is decreased at higher duty cycles above about 3.5 per cent.

Ignitron timers provide high accuracy of control. They are adjustable to pass current for any exact number of cycles from 1 to 15. For longer times, the SP-11-A is adjustable from 1 to 30 cycles. Welding machine current starts and stops at current zero eliminating line current transients.

LOW-ALLOY STEEL WELDING ROD

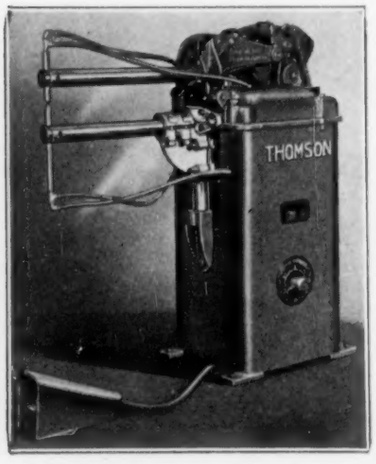
The Linde Air Products Company, Unit of Union Carbide and Carbon Corporation, has announced a new low-allow steel welding rod, Oxweld No. 32 C. M. S. Steel Welding Rod, for applications requiring welds of particularly high strength. It was developed primarily for insuring uniformly high-quality welds in high-strength steel pipe and plate. This rod develops an average tensile strength of 10,000 to 12,000 lb. per sq. in. greater than rods previously used for pipe welding, yet has sufficient ductility to meet any requirements.

Another outstanding characteristic of this new rod is its exceptional resistance to overheating in the molten state. Because of this, the rod is particularly suitable for use with the new four- and six-flame tips. When applying this rod, the weld-metal sets up more rapidly, making it easier to control the puddle on a curved or vertical surface. This makes greater welding speeds possible and also affects a reduction in gas consumption per weld.

POWER DRIVEN SPOT WELDER

Unlike many motor driven spot welders which are essentially foot operated machines with motor drives added, this welder is designed specifically to be power driven. All parts have the necessary bulk and strength to stand up under constant operation in production shops working in sheet metals or stampings.

The G Series Welder is available in three standard throat depths and four transformer capacities and has a speed range wide enough to adapt it to the pace of any production line. The choice of throat depths is 12, 18 or 24 inches and the transformer capacities are 20, 30, 40 or 60 kva. In each size, the transformer is water cooled to operate continuously at full load without overheating.



HELMET

A new type of Head and Face Protection comprising a Welding Helmet and Skullguard, has been added to the line of Welding Helmets and Hand Shields manufactured by The Fibre-Metal Products Co., Chester, Pa.

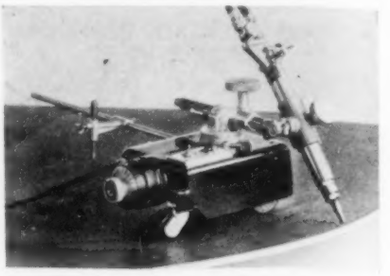
A unique feature of this combination is the fact that the Helmet can be detached from Skullguard when working in the shop, where these hazards are not present, and a new simplified adjustable headgear is quickly attached. Also, equipped with a new patented headgear adjustment friction joint which permits welder to adjust tension between helmet and headgear as desired.

ATOMIC HYDROGEN WELDING EQUIPMENT

A new atomic-hydrogen arc-welding equipment, especially suitable for the welding of special alloys and thin sections difficult or impossible to weld by other methods, has been announced by General Electric. The equipment is particularly useful where a fusion weld is required; it produces a uniformly strong weld, free from porosity, and with an exceptionally smooth appearance. Some common specific applications are: the building up of broken or worn sections of molds, tools and dies; the addition of a different metal for hard surfacing and other special requirements; and the welding of light-gage stainless steel.

RADIAGRAPH

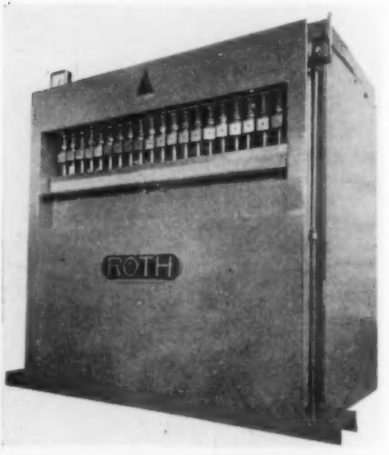
The Air Reduction Sales Company, 60 East 42nd Street, New York, N. Y., has added to their extensive line of famous gas cutting machines, the new light-weight No. 10 Radiagraph.



The exceptionally low price of the No. 10 Radiagraph places it within the purchasing range of most shops that cut steel slab and plates and provides for the industry an unprecedented value in flame cutting machines. The No. 10 will cut bevels up to 45° and needs no extra attachment for this type of work. Square edges and straight lines of any length desired may be produced and complete circles up to 85 inch diameter can be cut, using the radius rod and center point. Weighing only 41 pounds, it is extremely portable and can be carried from job to job with no appreciable effort.

ULTRASPEED SPOT WELDING

The new spot welder is a revolutionary hi-production spot welding method, allowing a welding speed from 10 to 20 spots per second, which is much faster than hydromatic welding, gun welding or any other spot welding method.



A number of individual spot welding electrodes (as many as required) are put under pressure simultaneously, each electrode having a separate pressure spring and individual current connection. The welding current is supplied to the individual electrodes in rapid succession (10 to 20 shots per second). A special current distributing unit of extremely simple design has been developed for this purpose. After *all* the welds are finished, the pressure is released simultaneously. Roth Welding Engineering Co., Inc., Detroit, Michigan.

• THE WELDING HANDBOOK • THE WELDING HANDBOOK • THE WELDING
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AMERICAN WELDING SOCIETY

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The greatest meeting in the history of the Society in conjunction with the Metal Congress and Exposition!

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Sections AMERICAN WELDING SOCIETY

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When in any city where sections of the Society are located—try to attend the meetings if held during your visit. This will widen your contacts in welding and enable you to interchange experience with others in similar lines of business. If no regular meeting date is given telephone the Secretary who will tell you.

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CHAIRMAN—M. C. SNEAD, Link Belt Co., 1116 Murphy Avenue, S. W.
ACTING SECRETARY—G. D. BARR, 139 Simpson St., N. W.

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CHAIRMAN—A. C. LEIGH, Ingalls Iron Works
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ROBERT M. WALLACE, The Griscom-Russell Company, Massillon, Ohio

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SECRETARY—CHESTER T. RAYMO, Chattanooga Boiler & Tank Company, 1011 East Main St., Chattanooga

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CHAIRMAN—R. E. MCFARLAND, Western Electric Company, Hawthorne Sta.
SECRETARY—M. S. HENDRICKS, Room 975, 608 So. Dearborn Street

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SECRETARY—ERIC O'HARA, Cincinnati Gas & Electric Company

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CHAIRMAN—F. L. PLUMMER, Consulting Engr., 1944 Standard Bldg.
SECRETARY-TREAS.—A. LESLIE PFEIL, Universal Power Corporation

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SECRETARY-TREAS.—Dan Ormsbee, The R. Hardesty Mfg. Company

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SECRETARY—H. A. PENNINGTON, A. B. King & Co., 196 Chapel Street, New Haven

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SECRETARY—J. S. WILLIAMS, P. R. Mallory & Co.

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SECRETARY—C. B. HERRICK, Lincoln Electric Co., 1818 Main St., Kansas City, Mo.

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SECRETARY—JOHN N. WOODS, Firestone Tire & Rubber Company

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CHAIRMAN—JOHN G. SHODRON, Marquette University
SECRETARY-TREAS.—GILBERT F. MEYER Machinery and Welder Corporation

MONTANA — **1st Wed.**
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SECRETARY—CHAS. F. GARMAN, P. O. Box 474, Fort Peck, Montana

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SECRETARY—G. V. SLOTTMAN, Air Reduction Sales Co., 60 East 42nd Street

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SECRETARY—ALEXIS CASWELL, Manufacturers Assoc. of Minn., 405 Marquette Ave., Minneapolis

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SECRETARY—G. A. ROSS, General Electric Co.

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SECRETARY—C. S. FREEMAN, The Lincoln Electric Company, Buffalo, N. Y.

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SECRETARY—G. E. MCGRATH, McGrath Welding Co., 4026 Nicholas, Omaha

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SECRETARY—W. MISKOE, Lincoln Electric Co.

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SECRETARY—H. E. HOPKINS, Arcos Corp., 401 N. Broad St.

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SECRETARY—PAUL W. JAMES, 30 Rowley St., Rochester

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CHAIRMAN—N. F. WARD, University of Calif., Berkeley, Calif.
SECRETARY—J. G. BOLLINGER, Air Reduction Sales, Park & Halleck Sts., Emeryville, Calif.

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CHAIRMAN—J. W. STEEN, Standard Oil Co., Taft, Calif.
SECRETARY—H. S. NIX, Box 1364, Taft, Calif.

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SECRETARY—A. R. ROSS, City of St. Louis, 304 City Hall.

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SECRETARY—RICH R. THOMPSON, Air Reduction Sales Co., Tulsa, Okla.

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CHAIRMAN—MARVIN COOK, Humble Oil & Refining Co., Houston
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Supplement to the Journal of the American Welding Society, August 1938

WELDING MANGANESE STEELS

A REVIEW OF THE LITERATURE TO JULY 1, 1937

By W. SPRARAGEN* and G. E. CLAUSSEN†

This report is prepared under the auspices of

THE LITERATURE DIVISION OF THE ENGINEERING FOUNDATION—
WELDING RESEARCH COMMITTEE

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NOTE: There are many other alloy steels containing manganese in addition to those discussed in the present review. Information on the welding of alloy steels containing manganese not included in the present review has been included in other reviews of literature on welding alloy steels that have been and are to be issued.

Summary

WELDING PEARLITIC MANGANESE STEELS

Mechanical Properties

Double V oxyacetylene welds in curved boiler plate 1 inch thick (0.12 C, 0.80 Mn, 0.24 Si, 0.029 P, 0.026 S, yield strength = 39,200 lb./in.², tensile strength = 63,500 lb./in.², notch impact value = 19.4 mkg./cm.²), had tensile properties equal to the base metal with excellent ductility and notch impact values of 6.2 mkg./cm.² The yield strength was slightly higher for the welds than the base metal up to 400° C.

The tensile and bend properties of welds in a steel containing 0.27 C, 1.54 Mn, 0.20 Si made with a "molybdenum alloy shielded arc" electrode were practically the same as base metal. The ductility was improved by stress annealing.

The Committee on Low-Alloy Steels placed steels containing 0.14–0.29 C, 1.36–1.64 Mn, 0.04–0.18 Si in the moderately air hardening class, the maximum hardness near the weld being over 96 B Rockwell. The Charpy notch impact value of arc welds in these steels was 21 to 36 ft.-lb.

Butt joints of 90% efficiency have been produced in oil well casing pipe 6 inches outside diameter, wall thickness about 0.40 inch, containing 0.22 C, 1.16 Mn, or 0.30–0.34 C, 1.65 Mn made with a coated electrode containing 0.26 C, 0.8 Mn, 0.04 Si, 0.029 S, 0.020 P.

Thermit welded 131-lb. rail (0.67 C, 1.32 Mn, 0.09 Si, 0.051 P) has good tensile and notch impact properties.

Recovery (including 14% Mn Steel)

Bare Electrodes.—The results of a number of scattered investigations show that up to 3% Mn, the recovery varies from 0 to 95%. Low carbon content in the electrode usually coincided with low manganese recovery. In the austenitic manganese steels (10–14 Mn, 1 C) the recovery of manganese is 79 to 89%, the recovery of carbon being 74 to 93%. In bare Ni-Mn austenitic electrodes, the recovery of manganese is 75 to 100% and of carbon 45 to 90%. Nickel is almost completely recovered and has no effect on recovery of manganese.

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Oxyacetylene Welding

The recovery of manganese in oxyacetylene welds varies from 34 to 99% (Mn range, 0.72 to 1.04%). The slightly carburizing flame is more effective in preventing loss of Mn than is the neutral. An oxidizing flame causes loss of manganese through oxidation.

Coated Electrodes

Reported recoveries from low-manganese electrodes vary haphazardly from 25 to 96%. In the medium range (1.55 Mn to 3.00 Mn) the recovery is 10 to 63%. Recoveries from high-manganese (10 to 14%) electrodes are high: 73 to 97%, the carbon recoveries also being high.

General Observations

One author states that suitable oxyacetylene welding rods for welding steels containing 1 to 2% Mn are Mn-V, Mn-W and Mn-Mo. Another recommends electrodes containing Mn, or Mo, or Ni-V.

There is slight air hardening near the weld in oxyacetylene welding aircraft steel containing 0.30 C max., 0.35 Si max., 1.75 Mn max., especially if the carbon and manganese are on the high side, but there is none with plain carbon steel (0.20–0.30 C, 0.60 Mn max.). It is recommended that large sections of steel containing 0.25–0.35 C, $1^1/_4$–$1^3/_4$ Mn be preheated to 150–260° C. (300–500° F.).

Manganese is often recommended as an addition to gas welding rods and electrodes.

Forge Welding

Manganese in steel has not caused forge welders much trouble. In fact, for water gas welding steel with 0.30 C, 0.20 Si, 0.06 P, 0.03 Si one author found that 1% Mn had to be added. The MnO formed a fluid silicate with the finely dispersed particles of silica.

Resistance Welding

Flash welding raises the strength but lowers the ductility of rails containing 0.44–0.46 C, 1.01–1.03 Mn, 0.038–0.054 Si, 0.070–0.076 P, 0.059–0.110 S. The Izod fracture showed a coarser grain size in the weld than in the unaffected rail but the notch impact value was practically the same.

Flame Cutting

Steels $^1/_2$ inch thick containing 0.12 C, 1.00 Mn, 0.62 Si, 0.26 Cu, 0.04 Ni, 0.00 Cr, 0.088–0.098 P, 0.024 S offer no difficulty to flame cutting. The depth of the heat-affected zone was 0.04 inch.

WELDING 14% Mn STEEL

Oxyacetylene Welding

Ni-Mn steel can be both arc and oxyacetylene welded, whereas plain 14% Mn steel can be best arc welded. Excellent results have been obtained with a filler rod of 18–8 or 25 Ni steel. Oxyacetylene-welded Ni-Mn steel frogs (0.6–0.9 C, 0.60–0.85 Si, 2.5–3.5 Ni, 11.0–13.5 Mn) have been in service two years without cracks. The welds were peened hot, and no effort was made to "skip about" in welding.

Metal Arc Welding

One commercial electrode for 14% Mn steel contains 1.3 C, 0.35 Si, 5.0 Ni, 14 Mn. Arc voltage is 30, and the current is 75–100 amp. for $^1/_8$-inch electrodes, 175–225 amp. for $^1/_4$-inch electrodes. If porosity is to be avoided, weaving is essential. Peening prevents crater cracks. A wandering sequence is best. The bare Ni-Mn electrode is easier to deposit than the coated.

The 18–8 electrode has often been used for 14% Mn steel. For switch points it is recommended that the part to be surfaced be prebent $^1/_2$ to $^3/_{16}$ inch and surfaced with a few layers of 18–8 electrodes. The deposit straightens the point. No metal should be deposited on 14% Mn frogs until the brittle, work-hardened surface has been ground off.

Mechanical Properties (Hardness)

The mechanical properties of welds in rolled 14% Mn steel made with a coated Ni-Mn electrode, reported by one author are:

Tensile strength	=	105,000 lb./in.^{2}
Elongation	=	30%
Cold bend angle	=	90° (no details)

Another author reported a tensile strength of 82,500 lb./in.^{2}, elongation = 9.2% in the length of the weld, reduction of area = 6.0% for a weld made with a bare electrode in a rolled rail containing 1.00 C, 0.40 Si, 12 to 13 Mn (tensile strength = 92,000 lb./in.^{2}, elongation = 11.3% in 5 diameters, reduction of area = 23%). The strength of 14% Mn castings is lower than that of rolled products.

Microstructure

Welds in heat treated wrought 14% Mn steel are subject to the same microstructural changes as the cast steel. The deposits consist of coarse columnar grains with dendritic markings and a small amount of free carbide. Fine, intercrystalline cracks were observed in the heat-affected zone, which were said to be caused by the high thermal gradient in the weld, which, in turn, was related to the low thermal conductivity of 14% Mn steel. A hot peened weld contained slip bands in the lower layers.

The presence of nickel in the Ni-Mn electrode results in a transition zone between deposit and base metal. If the carbon content of the electrode is held as low as possible, the carbon content of the transition zone is diluted, so that carbide precipitation is reduced to a minimum.

The microstructure of welds between 14% Mn steel and other steels may involve transition zones in which a change of phase occurs as well as a change in concentration.

Flame Cutting

Manual cut surfaces are coated with ledeburite (high carbon brittle eutectic), which sensitizes the surface to cracks. No ledeburite was observed on machine cut surfaces, the hardness of which was 320 Brinell (base metal = 220 Brinell). The heat-affected zone in flame cut 14% Mn steel is not so deep as in mild steel because the thermal conductivity of the 14 Mn steel is low. If the cutting torch is followed by a stream of water, the edge remains austenitic but, nevertheless, carbide precipitation occurs in the grain boundaries. Therefore, one author believes that flame cut 14 Mn steel should be heat treated.

WELDING NICKEL-MANGANESE STEELS

The welding and flame cutting of steel $^1/_8$ to $^3/_8$ inch thick containing 0.25–0.40 C, 10–12 Ni, 6–8 Mn to itself and to mild steel for transformer covers are described by one author. Heavy coated 18–8 electrodes are used

with 10 to 15% higher current than for mild steel electrodes. The electrode should contain 17–19 Cr, 7.50–10 Ni, 0.06–0.15 C. The welded joints were as strong as, or stronger than, mild steel and had better ductility. There was no difficulty in flame cutting.

WELDING COPPER-MANGANESE STEELS

Butt welds in steel containing 0.25 C, 1.35 Mn, 0.53 Cu (86–88 B Rockwell) made with a coated low-carbon electrode have a tensile strength of 82,850 lb./in.², free-bend elongation = 40.4%, and 88–90 B Rockwell. Welds made with a coated low-molybdenum electrode had 86,020 lb./in.² tensile strength, 51.2% free-bend elongation and 86–92 B Rockwell. The welding procedure is the same as for mild steel, the best welding properties being obtained with 0.25 C or slightly less, and with the manganese content nearer 1.25 than 1.75%.

WELDING CU-MN-NI STEELS

Oxyacetylene double-V butt welds were made in a steel 0.59 inch thick using a Cu-Mn-Ni steel rod. The weld had higher strength than base metal, but the notch impact value was low. Normalizing raised the notch impact value.

WELDING CU-MN-CR STEELS

Excellent tensile, bend, and impact test results have been obtained from V butt welds made with a shielded arc electrode in low-alloy steel 0.39 inch thick containing 0.18 C, 0.37 Si, 1.08 Mn, 0.43 Cr, 0.57 Cu.

WELDING CU-SI-MN STEELS

Unmachined, multi-layer butt welds made with covered electrodes and backing strip in cross-shaped reinforcing bars 0.22 C, 0.9 Si, 0.5 Mn, 0.5 Cu) had about the same properties as unwelded bars. The microstructure was fine grained.

WELDING CU-SI-MN-MO STEELS

Flame cutting steel 0.39 inch thick containing 0.13 C, 1.00 Mn, 0.60 Si, 0.42 Cu, 0.1 Mo had no effect on tensile strength, elongation or reduction of area.

WELDING CR-MN-SI-STEELS

As with most low-alloy structural steels, the mechanical and welding properties of Cr-Mn-Si steel depend on the carbon content.

Tensile properties slightly less than the base metal with good ductility on steel containing 0.20 C, 1.04 Mn, 0.51 Cr, 0.91 Si have been obtained with a molybdenum alloy electrode.

Up to 0.15 C another author states the Cromansil steels have no air hardening tendencies. Butt welds in low carbon Cromansil had a yield strength = 63,000 lb./in.², tensile strength = 86,00 to 98,000 lb./in.², bend elongation = 20 to 35%. Effective coatings to preserve the alloying elements in Cromansil electrodes may consist of a purely mineral slag: calcium iron silicate, which has a low melting point.

Welding Manganese Steels

INTRODUCTION

Two reviews of literature on the welding of manganese steels have been made prior to the present review. (Welding Special Ferrous Alloy Castings, AMERICAN WELDING SOCIETY JOURNAL, **16** (6) Suppl., 5–9, June 1937; The Effect of Total Carbon and Manganese on Welded Joints in Low-Carbon Steel, **16** (9) Suppl., 23–32, Sept. 1937.)

In the earlier reviews the mechanical properties and hardness of welded pearlitic manganese steels as well as the welding of cast 14% Mn steel were discussed. The present review extends the scope of the previous review on pearlitic manganese steels to include the effect of manganese on reactions in the weld puddle, and, in a separate section, summarizes available information on 14% Mn steel welding apart from castings. Separate sections have been allotted to pearlitic manganese steels containing other alloying elements. Pearlitic manganese steels are usually understood to contain 1.0 to 2.0% Mn, but steels with lower manganese content also are considered, particularly in the section on recovery. The recovery of manganese from welding rods for 14% Mn steel has been summarized in the section on pearlitic manganese steels.

The effects of manganese on solid steel have been discussed in the earlier review on pearlitic manganese steels. Although silicon and manganese are quite unlike in their effects on solid steel, they perform the same function as deoxidizers in liquid steel. Manganese reacts with FeO to form MnO (melting point = 1600° C.) or, if silicon is present, silicates: $MnO{\cdot}SiO_2$ (decomposes at 1285° C.), $(MnO)_2{\cdot}SiO_2$ (decomposes at 1365° C.), and $(MnO)_2{\cdot}FeO{\cdot}SiO_2$ (melting point about 1300° C.). Between 55 and 70% MnO, mixtures of MnO and SiO_2 melt between 1225° and 1300° C. The products of deoxidation with manganese are considered to coalesce with particular rapidity and to rise rapidly into the slag. The recovery of manganese from 80% ferromanganese has been reported to be 80 to 90% in the ladle and 60 to 90% in the furnace. The boiling point of manganese (760 mm. mercury) is said to be 1900° C. (boiling point of iron is 3200° C.).

WELDING PEARLITIC MANGANESE STEELS

Mechanical Properties

Since the preparation of the earlier reviews, some new information on the properties of pearlitic manganese steels has appeared which, together with some results that were not pertinent to the earlier review, are outlined below.

Single beads of covered electrode weld-metal were deposited by W. H. Bruckner (private communication, June 1938, and A. S. T. M. preprint 36, 1938) at a speed

of 6 inches/min. 180–190 amp. D.C.) down the middle of the length of 3 x 6 x $^1/_2$ inch ground plates, Table 1.

Table 1—Single Bead and Weld Quench Tests of Low Alloy Manganese Steels. Bruckner

			Vickers Hardness—10 Kg. Load Maximum Hardness of Heat-Affected Zone				Half Size Charpy Value, Ft.-Lb.		
C	Mn	Si	Base Metal	No Preheat	150° C. Preheat	260° C. Preheat	375° C. Preheat	Base Metal	After "Weld Quench"	Per Cent of Base Metal
0.24	0.48	0.23	143	224	206	193	174	9	9	100
0.27	0.74	0.21	172	287	...	206	200	19	9	47
0.29	1.06	0.25	181	312	246	233	224	22	7	32

The maximum hardness in the heat-affected zone increased with the manganese and carbon contents and decreased as the preheating temperature was raised. Half-size Charpy specimens of these steels were heat treated to secure a grain size and microstructure identical with that in the zone of maximum hardness of the unpreheated single bead specimens. The Charpy value of these "weld quench" specimens decreased as the manganese content increased, compared with the Charpy value of base metal.

Continuing their tests on the sensitivity of alloy steels to welding cracks (see review of literature on Welding Chromium Steels, American Welding Society Journal, **17** (7) Suppl. pg. 23, reference 110), Bardenheuer and Bottenberg[138] determined the sensitivity to welding cracks (Müller clamping apparatus) of the three steels 0.04 inch thick listed in Table 2. The

Table 2—Sensitivity to Welding Cracks of Low Alloy Manganese Steels. Bardenheuer and Bottenberg[138]

C	Si	Mn	P	S	Tensile Strength, Lb./In.^{2}	Elongation, % in 8 Inches	Percentage of Length of Weld Occupied by Cracks
0.38	0.20	1.20	0.058	0.034	102,000	18.0	19
0.50	0.30	1.22	0.043	0.028	123,000	13.5	29
0.34	0.22	1.40	0.074	0.030	103,000	18.3	54

steels were high frequency induction furnace melts and were left-hand welded with a neutral flame. The consumption of filler rod (0.05 inch diameter) was 1 gm. in 2 inches of weld. Since there is little practical welding difficulty if the sensitivity is 25% or less, the first steel in Table 2 is satisfactory.

Double V oxyacetylene welds in curved boiler plate 1 inch thick (0.12 C, 0.80 Mn, 0.24 Si, 0.029 P, 0.026 S, yield strength = 39,200 lb./in.^{2}, tensile strength = 63,500 lb./in.^{2}, notch impact value = 19.4 mkg./cm.^{2}) were made by Czternasty[1] using strips of base metal as filler rod. The weld contained 0.13 C, 0.48 Mn, 0.08 Si, 0.043 P, 0.028 S, the high phosphorous content being due to absorption from flame or to segregation in the plate. The welded joints had a yield strength = 40,500 lb./in.^{2}, tensile strength = 63,500 lb./in.^{2}, 38% elongation, 180° and 41% cold bend angle and elongation, and notch impact value = 6.2 mkg./cm.^{2} At 300° C. the yield strength was 27,000 lb./in.^{2} unwelded, 30,000 lb./in.^{2} welded. At 400° C. the yield strength was 20,000 lb./in.^{2} for unwelded plate, 24,000 lb./in.^{2} for weld.

The tensile strength, bend elongation and notch impact value of right- and left-hand oxyacetylene welds in medium carbon steel made with two rods, Table 3, were maximum in Stursberg's[2] tests when the ratio of oxygen to acetylene by volume (mixture ratio) was 0.9 to 1.1. The reduced section tensile specimen for the welds was 0.16 inch thick, 0.55 inch wide, 0.59 inch parallel section. The notched face of the notch impact specimen was only 0.16 inch wide, otherwise the specimen was identical with the standard German round notch specimen (notch on side of weld). The welds were of the V butt type with reverse pass of the torch without addition of filler rod, but carburizing flux technique was not used. The hardness of the weld-metal was the same as plate if the flame contained 2% excess acetylene. The notch impact value was 3 to 4 mkg./cm.^{2} at a mixture ratio of 1.6, and was reduced to 1 to 2 mkg./cm.^{2} at a ratio of 0.9. The bend elongation at a mixture ratio of 0.9 was 11 to 15%. The tensile strength at the mixture ratio corresponding to maximum notch impact value was about the same as base metal.

The tensile and bend properties of welds in a steel containing 0.27 C, 1.54 Mn, 0.20 Si made with a "molybdenum alloy shielded arc" electrode, according to Jen-

Table 4—Tensile and Bend Properties of Arc Welded Manten. Jennings[3]

Specimen	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, % in 2 Inches	Free-Bend Elongation, %
Unwelded base metal	55,000 to 65,000	80,000 to 90,000	20 to 25	..
As welded	53,000	90,000	15	32
Welded and stress annealed at (650° C. (1200° F.)	51,000	88,000	20	40

Table 3—Oxyacetylene Welding Rods Containing 1 to 2% Mn. Stursberg[2]

Specimen	C	Mn	Si	P	S	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, %*	Bend Angle, Degrees	Bend Elongation, %**	Notch Impact Value, Mkg./Cm.^{2}	Brinell Hardness
Plate 0.24 inch thick	0.35	0.65	0.18	0.033	0.034	51,000	83,000	24.3	180	36.7	8.2	168.5
Plate 0.59 inch thick	0.38	0.83	0.23	0.027	0.022	59,800	90,500	22.4	180	43.3	8.3	183
Rod 5	0.20	1.05	0.66	0.012	0.021	....	†99,000(0.9)	..	...	†36 (1.0)	†9.1 (1.05–1.1)	†170 (1.0)
Rod 6	0.30	2.03	0.17	0.016	0.022	....	†96,500(0.9)	..	...	†36 (1.0–1.1)	†8.8(1.0)	†170 (1.0)

* Gage length = 5.5 inches for 0.24-inch plate; = 4 inches for 0.59-inch plate.
† Weld.
** For unwelded plate, plunger thickness = 3 T (T = plate thickness); for welds, plunger thickness = 0.59 inch; specimens were machined to 0.20 inch thick; gage length = 0.59 inch; cracks, if any, had to be 0.02 inch wide.
( ) = mixture ratio.

nings,[3] Table 4, were practically the same as base metal. The ductility was improved by stress annealing. The Committee on Low Alloy Steels[4] placed steels containing 0.14–0.29 C, 1.36–1.64 Mn, 0.04–0.18 Si in the moderately air hardening class, the maximum hardness near the weld (no details) being over 96 B Rockwell. The Charpy notch impact value of arc welds in these steels was 21 to 36 ft.-lb.

Covered electrodes (0.16 inch diameter, 0.08 C, 0.18 Mn in weld) were superior to bare in the tests of arc-welded rails, Table 5, made by Csilléry and Péter.[5]

Table 5—Arc-Welded Rails. Csillery and Peter[5]

Specimen	C	Mn	Si	S	P
Softer rail	0.42	0.77	0.16	0.021	0.029
Harder rail	0.53	1.05	0.12	0.025	0.043
Foot strap	0.04	0.41	0.05	0.017	0.025

Katona joints were made (butt-welded head, fillet-welded foot strap), and were cooled in sand after being welded. The maximum hardness in the heat-affected zone of both rails was 264 Brinell. Wear tests revealed no difference between weld-metal and base metal in the joint, and joints in both rails had practically the same static and impact bend properties. The greater the variations in hardness in the joint, the lower were the bend properties.

Tests reported by Bierett,[6] Table 6, show that the maximum hardness in the heat-affected zone of a plate 1.73 inches thick, 10 inches wide, containing 0.20 C, 1.38 Mn, 0.48 Si, 0.08 Cu created by a single bead deposited in the center (speed of welding and other details not stated) decreased as the diameter of the electrode increased.

Table 6—Effect of Diameter of Electrode on Maximum Hardness in Heat-Affected Zone. Bierett[6]

Diameter of electrode, inch	0.12	0.16	0.20	0.24
Maximum Brinell hardness in Heat-affected zone	365	330	300	295
Percentage increase above unaffected base metal	130	100	90	85

Basing efficiency on the tensile strength of the unwelded pipe, Hodell[7] found that the efficiencies of welded joints in oil well casing 6 inches outside diameter, wall thickness about 0.40 inch, containing 0.22 C, 1.16 Mn, or 0.30–0.34 C, 1.65 Mn made with a coated electrode containing 0.26 C, 0.8 Mn, 0.04 Si, 0.029 S, 0.020 P were:

Bell-and-spigot joint, 2 beads—100%
Bell-and-spigot joint, 1 bead — 84.3%
Butt joint — 90%

Fractures occurred in the weld, the tensile strength of the double bead bell-and-spigot joints being 92,000 to 94,000 lb./in.^{2} in both steels.

Table 7—Tensile Properties of Arc-Welded C-Mn Sheet. Hinde[8]

Specimen	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, % in 2 Inches	Location of Failure
Unmachined	60,500	94,000	14	Base metal
Ground flush	64,000	94,000	17	Base metal
Ground flush and hole drilled in weld	80,500	110,000	6 (10% in 1/2 inch)	Weld

The tensile properties of 16-gage butt-welded sheet containing 1 1/2 Mn, <0.30 C, according to Hinde,[8] Table 7, were not affected by grinding the weld flush. Covered electrodes (14 gage) were used. Hinde mistakenly inferred that the yield ratio of weld-metal was higher than that of base metal.

Thermit welded 131-lb. rail (0.67 C, 1.32 Mn, 0.09 Si, 0.021 P, 0.051 S) has good tensile and notch impact properties, according to Clarke,[9] Table 8. The specimens were cut parallel to the length of the rail.

Table 8—Thermit Welded Rail. Clarke[9]

Location of Specimen	Welded or Unwelded	Elastic Limit, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, %	Reduction of Area, %	Brinell Hardness	Charpy Impact Value, Ft./Lb.
Head	Unwelded	44,000	133,200	14	19.2	260	2.6
Head	Welded	59,000	132,800	8.5	19.8	292	2.8
Base	Unwelded	59,000	133,800	14	23.0	...	2.4
Base	Welded	62,000	135,000	8.5	21.3	286	5.1

Rarely does mild steel contain less than 0.3% Mn. It is interesting, therefore, that Wilhelm's[10] steels, Table 9, containing unusually low manganese had the same welding properties as steel containing the usual quantity of manganese. The steel was made from scrap in a basic open-hearth. No manganese additions were made, and anthracite coal was used for recarburization. Although not stated, the silicon content was probably nil. A full section tension specimen was used for the unwelded plate. The reduced section specimen for the welds was 0.78 inch wide at the narrowest section, the weld, and 1.18 inches wide at the widest section. There was no parallel section. The fillet radius being 0.78 inch. The standard German round-notch impact specimen was used. The atomic hydrogen weld in the thin plate was made without filler rod; a special rod was used for the thick plate. The yield strengths of the forge welded specimens were 40,400 lb./in.^{2} (top) and 38,100 lb./in.^{2} (bottom); the elongation in 0.78 inch was 12.5% (top) and 17.5% (bottom).

In general, the plates from the bottom of the ingot had better welding characteristics and produced stronger welds than plates from the top. In all welds the penetration was good and the structure was the same as in welds in manganese-deoxidized steels. There was no difference in welding characteristics between samples from center and edge of plate; consequently, any segregation that may have existed had no effect.

RECOVERY (INCLUDING 14% Mn STEEL)

When a welding rod containing manganese is deposited, manganese may vaporize as gaseous Mn or as a gaseous Mn compound, or the manganese may combine with oxygen, silica or sulphur, or it may remain in the steel.

The vapor pressure of Mn in dilute solution in steel, even in 14 Mn steel, must be much lower than the vapor pressure of pure Mn. Consequently, loss of Mn by vaporization as Mn during welding is not so likely as the relatively low boiling point of Mn might lead one to expect. An increase in Mn in the welding rod increases the vapor pressure of Mn in the rod. Vaporization of Mn as a gaseous compound has never been observed in welding. The boiling points of the manganese oxides, carbides (apparently Mn_3C has no lower boiling or decomposition point than Mn, Ruff), and silicates are higher than Mn. Newell[13] believed that manganese carbonyls

Table 9—Low-Manganese Steels Used by Wilhelm[10] and Mechanical Properties of Welds

Plate Thickness, Inch	Position in Ingot	Composition of Unwelded Steel C	Mn	P	S	Cu	Ni	Cr	As	Sn	N_2	O_2	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 0.78 In.
0.12	top	0.11	0.20	0.025	0.065	0.24	..	..	..	..	.....	.....	....	39,500	..
0.12	bottom	0.06	0.19	0.015	0.028	0.23	..	..	..	..	.....	.....	....		
0.39	top	0.08	0.17	0.015	0.065	0.25	0.15	0.03	..	..	0.004–0.0046	0.0087–0.0098			
0.39	bottom	0.055	0.17	0.015	0.033	0.25	0.17	0.03	0.05	0.02	0.0029–0.0032	0.013–0.019	38,500	43,500	26

Position of Plate in Ingot	Welds in 0.12-Inch Plate: Tensile Strength, Lb./In.²	Bend Angle, Degrees	Location of Bend Fracture	Welds in Plate 0.39 Inch Thick: Tensile Strength, Lb./In.²	Bend Angle, Degrees To First Crack	To Fracture	Location of Bend Fracture	Notch Impact Value, Mkg./Cm.² at: −20° C.	0° C.	+20° C.	+50° C.	Type of Weld
Top	61,100	>180	no fracture	59,500	28	85	in weld	0.8	0.8	3.1	12.4	Oxyacetylene with additions of charcoal iron rod
Bottom	68,000	>180	no fracture	57,000	22	93	in weld					
Top	59,000	145	heat-affected zone	66,000	21	91	in weld	1.2	2.0	4.2	5.7	D.C. arc with thin coated electrodes
Bottom	63,500	>180	no fracture	66,000	35	91	in weld					
Top	65,500	161	mainly in middle of weld	73,000	59	97	in weld	1.2	1.7	3.4	8.1	Atomic hydrogen
Bottom	67,300	180	....	73,600	90	137	in weld					
Top	....	...	....	50,800	126	>180	....	2.5	2.9	11.2	12.3	Forge weld
Bottom	....	...	....	50,800	...	>180	no fracture	1.0	2.0	11.7	13.4	

Table 10—Recovery of Manganese from Bare Electrodes. (See Tables 11 to 17)

Manganese, % Electrode	Manganese, % Weld	Carbon, % Electrode	Carbon, % Weld	Silicon, % Electrode	Silicon, % Weld	Recovery of Manganese, % of Electrode	Recovery of Carbon, % of Electrode	Notes	Investigator
0.12	0.04	1.07	0.82	0.20	Trace	33	77	Diameter of electrode = 0.16 inch; single bead on mild steel	Dahl and Sandelowsky[14]
0.25	0.19	1.05	0.68	0.19	0.14	76	65	Single bead on a bar of copper	Rapatz[15]
0.34	0.08	0.08	0.04	0.01	0.01	24	50	Single bead on a bar of copper	Rapatz[15]
0.34	0.10	0.06	0.00	0.13	Trace	29	0	See 0.12 Mn	Dahl and Sandelowsky[14]
0.41	Trace	0.068	Trace	0.052	0.010	0	0	D.C.	Schoenmaker[16]
0.42	0.40	0.11	0.06	0.01	0.01	95	55	Electrode negative	Zeyen[17]
0.44	0.30	0.57	0.14	0.08	Trace	68	25	See 0.12 Mn	Dahl and Sandelowsky[14]
0.45	0.30	0.05	0.00	0.08	Trace	67	0	See 0.12 Mn	Dahl and Sandelowsky[14]
0.46	0.30	0.08	0.01	0.00	Trace	65	13	See 0.12 Mn	Dahl and Sandelowsky[14]
0.47	0.08	0.14	Trace	0.027	0.008	15	0	D.C.	Schoenmaker[16]
0.50 to 0.72	0.11 to 0.18	0.10 to 0.17	0.05 to 0.14	..	..	about 25	50 to 80	....	Spraragen[18]
0.55	0.49	0.85	0.60	0.35	0.18	89	71	All-weld-metal	Csilléry and Péter[5]
0.57	0.25	0.17	0.10	0.14	0.09	44	59	All-weld-metal	Viall[19]
0.59	0.48	0.55	0.29	0.13	0.08	81	53	Single bead on a bar of copper	Rapatz[15]
0.73	0.24	0.08	0.05	0.13	0.02	33	63	Single bead on a bar of copper	Rapatz[15]
0.77	0.43	0.74	0.22	0.024	0.020	56	30	D.C.	Schoenmaker[16]
1.01	0.85	0.39	0.21	0.12	0.03	84	54	All-weld-metal	Viall[19]
1.68	1.54	0.09	..	..	..	92	..	Weld in steel of same analysis	Schuster[20]
3	1.5 to 2	..	..	..	..	50 to 67	..	All-weld-metal	Sillars[21]
11.75	10.2	0.95	0.70	0.21	0.04	87	74	See 0.12 Mn	Dahl and Sandelowsky[14]
12.5	11.0	0.97	0.76	0.79	0.41	88	78	Thick deposit on steel with 1 to 1.35 C, 12 to 14 Mn, 6.3 to 0.8 Si	Hall[22]
12.6	11.0	1.14	0.92	..	..	87	81	Thick deposit on steel with 1.19 C, 11.9 Mn	Hall[23]
12.8	11.4	0.92	0.78	..	..	89	85	Thick deposit on steel with 1.25 C, 12.6 Mn	Rehfuss[24]
13.0	13.0	1.00	1.00	(0.15 Cr) 0.25	0.08	100	100	Weld in steel with 1.00 C, 12–13 Mn, 0.40 Si	Csilléry and Péter[25]
13.6	10.7	0.87	0.74	0.34	0.14	79	85	1 layer on mild steel (0.12 C); electrode diameter = 0.20 inch	Zeyen[26]
13.6	12.0	0.87	0.81	0.34	0.15	88	93	3 superposed beads on mild steel (0.12 C)	Zeyen[26]
14.9	13.1	1.11	0.86	0.25	0.11	88	76	Single bead on a bar of copper	Rapatz[15]

Table 11—Recovery of Manganese from Manganese Steel Electrodes Containing Nickel (probably bare)

Manganese, % Electrode	Manganese, % Weld	Carbon, % Electrode	Carbon, % Weld	Nickel, % Electrode	Nickel, % Weld	Recovery of Manganese, % of Electrode	Recovery of Carbon, % of Electrode	Recovery of Nickel, % of Electrode	Notes	Investigator
13 to 14	10.4	0.75 to 0.80	0.41	3.0 to 3.5*	3.11*	75 to 80	45	100	Thick deposit on steel with 1 to 1.35 C, 12 to 14 Mn, 0.3 to 0.8 Si	Hall[22]
14.0	12.8	1.3	1.04	5.0†	4.37†	92	80	88	Deposit on 14% Mn rail	Tracy and Tilton[36]
14.5	12.7	0.77	0.53	3.38	3.09	88	69	91	Thick deposit on steel with 1.25 C, 12.6 Mn; rod diameter = 3/16 in.	Rehfuss[24]
12 to 15	12.6	0.70 to 0.80	0.62	2.75 to 3.50	3.25	100	75 to 90	100	Thick deposit on steel with 1.19 C, 11.9 Mn	Hall[23]

* Electrode contained 0.50 Si; deposit contained 0.17 Si.
† Electrode contained 0.35 Si; deposit contained 0.53 Si.

Table 12—Recovery of Manganese from Bare Electrodes. Pilarczyk[11]

Electrode	Carbon Weld	Manganese Recovery, %	Manganese Electrode	Manganese Weld	Manganese Recovery, %	Silicon Electrode	Silicon Weld
0.14	0.03	21	0.41	0.17	41	..	..
0.15	0.03	20	0.56	0.23	41	..	..
0.17	0.04	24	0.97	0.35	36	0.08	0.01
0.21	0.04	19	0.58	0.18	31	0.32	0.02
0.22	0.05	23	1.04	0.43	41	0.28	0.03
1.04	0.67	65	0.25	0.23	92	..	..
1.03	0.58	56	0.69	0.60	87	..	..
0.09	0.03	33	0.27	0.13	48	..	..
0.86	0.47	55	0.28	0.23	82	..	..

are formed in the arc and vaporize but he had no experimental evidence whatever.

If the manganese combines with oxygen, silica, sulphur or some other substance, the compound may appear in the slag or remain in the steel as an inclusion. As an inclusion in the steel, the manganese may or may not appear in the reported composition of the weld deposit, depending on the solubility of the compound in the analytical reagent. In this discussion of recovery it is assumed that the manganese contents reported by the investigators are manganese in solid solution or as carbide in the filler rod and deposit. The recovery of metallic and carbide manganese is distinguished from loss of Mn as slag or vapor. Recovery is expressed as the percentage of the metallic and carbide manganese in the electrode that is recovered in the same forms in the weld deposit. In the absence in every instance of information on the composition and amount of slag, or the efficiency of deposition (ratio of weight of deposit to weight of filler rod used), all calculations of recovery are approximate. Since practically nothing is known about Fe-Mn-O and other reactions (rates, equilibria) at welding temperatures, nothing can be said about the probable effect of increasing manganese on recovery, apart from the experimental work that is summarized in the following sections.

Bare Electrodes

Information on the recovery of manganese from bare electrodes is summarized in Tables 10 to 16. Table 10 contains the results of a number of scattered investigations which show that up to 3% Mn, the recovery varies from 0 to 95%. Low carbon content in the electrode usually coincided with low manganese recovery. In the austenitic manganese steels (10–14 Mn, 1 C) the recovery of manganese is 79 to 89%, the recovery of carbon being 74 to 93% (omitting the exceptional results of Csilléry and Péter). In bare Ni-Mn austenitic electrodes, Table 11, the recovery of manganese is 75 to 100% and of carbon 45 to 90%. Nickel is almost completely recovered and has no effect on recovery of manganese.

Systematic investigations of some of the factors affecting manganese recovery from bare low- Mn electrodes have been made by Pilarczyk[11] and Losana.[12] The former deposited bare electrodes 0.16 inch diameter on plates containing 0.11 C, 0.60 Mn (no details). Table 12 shows that the recovery of manganese is greatly increased by increasing the carbon content of the electrode. The recovery of carbon depends only on the carbon content of the electrode not on the manganese content. The higher carbon steels have a relatively low melting point, which would act against loss of Mn by vaporization. Pilarczyk made a detailed study of the pressure of FeO, MnO, SiO_2 and CO as a function of the carbon content of steel up to 2000° C. Apart from showing that the pressures increased as temperature increased and as carbon content decreased, and that at the highest temperatures MnO had the highest pressure, CO the lowest, Pilarczyk's attempt to relate the recoveries to slag-metal equilibria was not successful.

The study of reactions demonstrated to Pilarczyk that the reaction between the welding atmosphere (air) and weld-metal was of basic importance to recovery. Although he was unable to perform test welding in different gases, he used bare electrodes, Table 13, that had been oxidized in refining to different extents. The oxidized melts resulted in lower recoveries of manganese and carbon than the deoxidized melts. In other words, the recovery of manganese depends on the degree of deoxidation of the rod or on the FeO content of rod and uncombined oxygen content of the atmosphere. Unfortunately, there is reasonable doubt whether Pilarczyk's analyses represented only uncombined manganese.

Table 13.—Effect of Refining Conditions in Steel Furnace on Recovery of Manganese from Bare Electrodes. Pilarczyk[11]

Electrode	Carbon Electrode	Carbon Weld	Manganese Electrode	Manganese Weld	Recovery of Manganese, %
Deoxidized with aluminum	0.86	0.47	0.27	0.27	100
Not deoxidized	0.86	0.30	0.28	0.26	93
Oxidized with ore	0.59	0.04	0.53	0.38	72
Deoxidized with aluminum and silicon*	0.60	0.23	0.53	0.44	83
Deoxidized with aluminum and silicon*	0.08	0.05	0.39	0.28	72
Not deoxidized	0.19	0.02	0.48	0.19	40

* Electrode contained 0.01 Si.

Table 14—Effect of Welding Conditions on Recovery of Manganese from Bare Electrodes. Pilarczyk[11]

Specimen	Electrode 0			Electrode 1			Electrode 2				Electrode 3				Electrode 4			
	C	Mn	R	C	Mn	R	C	Mn	R	Si	C	Mn	R	Si	C	Mn	R	Si
Analysis of electrode	0.09	0.43	..	0.14	0.73	..	0.39	1.10	..	0.07	0.68	0.74	..	0.15	0.93	0.16	...	0.19
High, narrow bead	0.02	0.22	51	0.03	0.29	40	0.10	0.62	57	0.02	0.23	0.42	57	0.03	0.43	0.17	100+	0.06
Broad, flat bead	0.02	0.25	58	0.03	0.29	40	0.11	0.61	56	0.02	0.23	0.38	51	0.05	0.42	0.15	94	0.04
Current = 95 amp.	0.03	0.24	56	0.03	0.29	40	0.08	0.55	50	0.01	0.24	0.48	65	0.03	0.46	0.19	100+	0.06
Current = 115 amp.	0.03	0.20	47	0.03	0.29	40	0.10	0.65	59	0.02	0.24	0.48	65	0.05	0.46	0.20	100+	0.07
Current = 160 amp.	0.03	0.24	56	0.02	0.29	40	0.10	0.61	56	0.01	0.24	0.44	60	0.03	0.45	0.21	100+	0.11
Long arc, 0.59 inch	0.03	0.10	23	0.03	0.17	23	0.03	0.37	34	0.01	0.09	0.38	51	0.02	0.31	0.15	94	0.05
Two beads superposed	0.03	0.17	40	0.03	0.21	29	0.05	0.61	56	0.01	0.25	0.50	68	0.06	0.52	0.16	100	0.10
Electrode positive	0.03	0.25	58	0.02	0.28	38	0.08	0.63	57	0.02	0.23	0.47	64	0.04	0.48	0.19	100+	0.06
Electrode negative	0.02	0.23	54	0.03	0.27	37	0.08	0.42	38	0.01	0.27	0.31	42	0.03	0.53	0.09	56	0.05

R = Recovery of manganese, %.

Different welding conditions, Table 14, were also investigated (no details). The lowest recoveries were obtained with a long arc. Straight polarity also resulted in low recovery of manganese. Hoffmann[27] stated that loss of Si, Mn and C from bare electrodes was 30% greater with straight than with reversed polarity. Welding current and shape of bead had little effect. The high recoveries with electrode 4 probably reflect pick up from base metal.

The effect of increase in arc length in decreasing recovery of manganese was confirmed by Losana,[12] Table 15. Bare electrodes 0.16 inch diameter, D.C., were deposited on mild steel. The current was about 100 amp. at 0.08 inch arc length, and about 200 amp. at 0.39 inch. The effect of arc length is not due primarily to increase the current, because the recovery of manganese increased as the electrode diameter increased, Table 16. The current was not stated; an automatic welder, D.C., was used and the length of arc and current was the same for all electrodes of the same diameter. The results suggest that the degree of exposure of the weld-metal to the air before or during passage from electrode to puddle is an important factor.

Table 15—Effect of Arc Length on Recovery of Carbon and Manganese from Bare Electrodes. Losana[12]

Arc Length, Inch	Electrode Contained 0.21 C, 0.92 Mn, 0.18 Si, 0.16 Ni				Electrode Contained 0.41 C, 0.82 Mn, 0.19 Si			
	% C in Deposit	Recovery of C, %	% Mn in Deposit	Recovery of Mn, %	% C in Deposit	Recovery of C, %	% Mn in Deposit	Recovery of Mn, %
0.08	0.092	44	0.102	11	0.128	31	0.122	15
0.20	0.034	16	0.040	4	0.051	13	0.041	5
0.39	0.018	9	0.008	1	0.023	6	0.009	1

Table 16—Effect of Diameter on Recovery of Manganese from Bare Electrodes. Losana[12]

Composition of Electrode			Percentage Manganese in Deposit			
C	Si	Mn	Electrode Diameter = 0.08 Inch	Electrode Diameter = 0.16 Inch	Electrode Diameter = 0.24 Inch	Average Recovery, %
0.19	0.13	0.28	trace	0.016	0.021	5
0.22	0.20	0.65	0.026	0.051	0.094	9
0.41	0.19	0.82	0.062	0.088	0.146	12
0.10	0.17	0.89	0.054	0.070	0.124	9
0.65	0.22	0.94	0.084	0.108	0.196	14
Average Recovery, %			5	9	17	10

Hodge[28] estimated that the recovery of manganese from bare electrodes containing 0.30 Mn may be 40%. Mild steel rods deposited by carbon arc in hydrogen, according to Tichodeev,[29] lose 80% of their manganese content. More than half the loss occurred at the end of the rod. Tichodeev believed that the same loss would occur in depositing bare electrodes in air. Tests by McCune[30] showed that 58% of the carbon and 65% of the manganese was recovered from bare electrodes containing 0.90–1.10 C deposited in air. Scarcely any effect on recovery of manganese and carbon was observed by Kessner and Specht[31] on cold working bare mild and low-alloy steel electrodes.

Oxyacetylene Welding

In fused beads made with rods containing up to 2% Mn and in V welds in 0.39-inch plate of the same composition as the rod (no details), Portevin and Leroy[32] found that manganese has no effect on the recovery of carbon. With increasing Mn the absolute loss of Mn

Table 17—Recovery of Manganese in Oxyacetylene Welding

Manganese, %		Carbon, %		Silicon, %		Recovery of Manganese, % of	Recovery of Carbon, % of		
Rod	Weld	Rod	Weld	Rod	Weld	Filler Rod	Filler Rod	Notes	Investigator
0.72	0.39	0.25	0.13	0.40	0.12	54	52	10% excess oxygen, all-weld-metal	Keel[33]
0.72	0.67	0.25	0.31	0.40	0.32	93	100+	Carburizing flame, all-weld-metal	Keel[33]
0.72	0.47	0.25	0.10	0.40	0.10	65	40	Neutral flame, all-weld-metal	Keel[33]
0.80	0.48	0.12	0.13	0.24	0.08	60	100+	Weld in plate of same composition	Czternasty[1]
0.85	0.45	0.45	0.13	0.25	0.02	53	29	All-weld-metal	Keel[33]
0.86	0.47	0.19	0.10	0.34	0.10	55	53	All-weld-metal	Keel[33]
0.91	0.53	0.60	0.35	0.20	0.08	58	58	Weld in round bar of same analysis as rod	Carnevali[34]
0.9	0.9	0.60	0.31	0.20	0.04	99	52	Weld in round bar containing 1.09 C, 0.79 Mn, 0.09 Si	Carnevali[34]
1.04	0.35	0.18	0.06	0.53	0.12	34	33	All-weld-metal	Keel[33]
11.5	9.60	1.10	1.00	0.08	0.05	84	91	Neutral flame	Dawson[35]
13.6	11.6	0.87	0.92	0.34	0.05	85	100+	1 layer on mild steel (0.12 C) rod diameter = 0.20 inch	Zeyen[26]
13.6	12.1	0.87	0.96	0.34	0.12	89	100+	3 layers on mild steel (0.12 C) rod diameter = 0.20 inch	Zeyen[26]
15.6	13.5	1.17	1.52	0.52	0.21	87	100+	Flame with excess acetylene	Dawson[35]

varied from nil with 0.05 Mn in the rod, to 0.12 with 1% Mn in the rod. The recovery varied with manganese content in the butt welds. The loss was 0.15 Mn at 0.5 Mn in the rod and plate, and was 1.10 Mn with 2.1 Mn in rod and plate. Silicon had no effect on the loss of Mn. As in the preceding section on bare electrodes, there was no indication that there was a limiting manganese content below which no loss in manganese is observed, nor was there any basis for believing that the absolute loss of Mn was independent of manganese content beyond a critical manganese content. Portevin and Leroy particularly emphasized the controlling effect of different periods of time and conditions of fusion on recovery of manganese (and carbon and silicon) from steels in oxyacetylene welding. Loss of manganese was attributed to oxidation.

Other investigators, Table 17, agree with Portevin and Leroy. The recovery of manganese from austenitic manganese steel rods is the same as from bare electrodes, namely 84 to 89%. The recovery of carbon is much higher and is under the control of the operator. According to McCune,[30] the recovery of manganese from rods containing 0.9–1.10 C (no details) is 70%, the carbon recovery being 63%. Tichodeev[29] found that the recovery of Mn in a neutral oxyacetylene flame is only 50%, when 0.16-inch rods containing 0.36 to 1.06 Mn were fused.

Table 18—Effect of Mixture Ratio on Manganese Recovery from Oxyacetylene Welding Rods. Stursberg[2]

	Rod 1		Rod 5		Rod 6	
Mixture Ratio	% Mn Lost	Recovery of Mn, %	% Mn Lost	Recovery of Mn, %	% Mn Lost	Recovery of Mn, %
0.8	0.11	60	0.19	78	0.35	83
0.9	0.11	60	0.20	77	0.49	76
1.0	0.11	60	0.29	69	0.47	64
1.2	0.11	60	0.37	62	0.90	56
1.4	0.16	40	0.39	60	..	..
1.6	0.14	48	0.44	55	1.4	31

Chemical Composition of Rods

Rod	C	Mn	Si	P	S
1	0.05	0.26	0.03	0.006	0.026
5	0.20	1.05	0.66	0.012	0.021
6	0.30	2.03	0.17	0.016	0.022

The effect of increasing mixture ratio on the manganese content of drops melted by means of an oxyacetylene torch from three filler rods, Table 18, and caught in a pail of water, according to Stursberg,[2] was to decrease the recovery of manganese. Mixture ratio was the ratio of oxygen to acetylene by volume. Rod 1 showed no change in carbon content as a result of melting if the mixture ratio was 1.0. The corresponding ratio for rods 5 and 6 was 0.94. The composition of the "neutral" flame depended on the carbon content of the rod rather than on the manganese. Supplying no details, Mercier[37] stated that 47% of the manganese, 56% of the silicon and 32% of the carbon was lost from a rod containing 1 Mn, 0.4 Si in oxyacetylene welding.

Coated Electrodes

Hodge[28] stated that the recovery of manganese from covered electrodes containing 0.07–0.20 Mn may be 60 to 86%. Other determinations are listed in Table 19. Reported recoveries from low-manganese electrodes vary haphazardly from 10 to 96%. The lime-dipped electrode had a medium recovery of manganese, no better than is expected of a bare electrode. Recoveries from high-manganese electrodes are high: 73 to 97%, the carbon recoveries also being high. The relatively poor recovery of manganese from some of the covered electrodes may be explained by welding conditions or by absorption of manganese by the slag. Obviously the composition and thickness of the coating are important factors in the recovery of manganese from covered electrodes, yet, with the exception of Losana, none of the investigators thought it necessary to state the composition of their coating.

Losana's[12] coatings consisted of ferromanganese (0.86 C, 0.46 Si, 75 Mn), or carbon and water glass (36° Be) and weighed 1/4 as much as the core rod, which was 0.16 inch diameter. The arc length and current (A.C.) were constant in the tests (no details). In none of his tests did Losana supply information on the relative weight or composition of the welding slags, nor was the weight of the deposit recorded. The calculated recov-

Table 19—Recovery of Manganese from Coated Electrodes

Manganese, % Electrode	Manganese, % Weld	Carbon, % Electrode	Carbon, % Weld	Silicon, % Electrode	Silicon, % Weld	Recovery of Manganese, % of Electrode	Recovery of Carbon, % of Electrode	Notes	Investigator
0.4	0.1	1.0	0.5	...	...	25	50	All-weld-metal	Newell[13]
0.41	0.20	0.068	0.031	0.052	0.011	49	46	A.C.	Schoenmaker[16]
0.47	0.45	0.14	0.09	0.027	0.010	96	64	A.C.	Schoenmaker[16]
0.70	0.50	0.11	0.02	0.13	0.02	72	18	Cored electrode 0.16 inch diameter deposited on mild steel	Dahl and Sandelowsky[14]
0.72	0.18	0.23	0.08	0.05	0.11	25	35	All-weld-metal	Csilléry and Péter[5]
0.77	0.70	0.74	0.38	0.020	0.018	91	51	A.C.	Schoenmaker[16]
1.55	0.97	0.22	0.065	0.27	0.04	63	30	All-weld-metal. Lime dipped electrode 0.16 inch diameter	Pohl[38]
2.0	0.2	1.0	0.3	..	..	10	30	All-weld-metal	Newell[13]
2.92	0.65	0.15	0.06	0.29	..	22	40	Wound with blue asbestos yarn	Lea and Parker[39]
3.0	0.5 to 0.7	..	..	..	..	17 to 23	..	All-weld-metal	Sillars[21]
10.51	10.19	0.99	0.71	..	..	97	72	Deposit on plain carbon steel rail	Pennington[40]
11.2	8.11	0.85	0.63	..	..	73	74	Deposit on mild steel electrode negative	Pennington[40]
11.2	8.11	0.85	0.83	..	..	73	98	Deposit on mild steel electrode positive	Pennington[40]
13.6	10.9	0.87	0.80	0.34	0.08	80	92	1 layer on mild steel (0.12 C); electrode diameter = 0.20 inch, D.C.	Zeyen[26]
13.6	12.1	0.87	0.94	0.34	0.10	89	100+	Ditto but 3 superposed beads	Zeyen[26]
13.6	9.8	0.87	0.87	0.34	0.07	72	100	1 layer on mild steel (0.12 C) electrode diameter = 0.20 inch A.C.	Zeyen[26]
13.6	12.2	0.87	1.08	0.34	0.08	90	100+	Ditto but 3 superposed beads	Zeyen[26]

eries, therefore, are coarse approximations. As ferromanganese is added to the water glass coating, Table 20, the absolute amount of manganese recovered increases at first slowly then rapidly. However, the percentage recovered is low and constant up to $1^1/_4$ to 4% Mn. The percentage recovered then increases abruptly to 70% with 5 to 8% Mn in the electrode. The recovery of carbon was practically complete at relatively low manganese contents, even if allowance is made for the carbon content of the ferromanganese.

The addition of carbon to the water glass coating, Table 21, increased the absolute amount of manganese recovered at first rapidly, then more slowly. The percentage recovered increased steadily as carbon was added to the coating. Even with 4% C in the electrode the recovery of manganese was only 34% in the higher manganese electrode. The carbon content of the deposit increased very slowly as carbon was added to the coating and the percentage recovered decreased. All told, Losana's tests show manganese to be a better coating constituent than carbon, if the coating consists mainly of water glass.

Later, Losana and Jarach[41] investigated the mutual effects of manganese, silicon and carbon on recovery, Table 22 (see Table 24 of review of literature on Welding Nickel Steels). The method of computing recoveries was the same as that used in the review of literature on Welding Nickel Steels. Two factors had to be neglected in the computation. First, the core rod contained Mn, Si and C, which was not considered in the computation. Second, metal from the coating tends to increase the weight of the deposit. Both factors act in opposite directions and are believed to be secondary in view of the fact that the composition and weight of the slag, and the weight of the deposit were not recorded.

Within the limits imposed on the computations, it is safe to conclude with the authors that:

1. With constant carbon and silicon contents in the coated electrode, an increase in manganese increases the percentage of Mn, Si and C recovered. The increase in manganese pick up is observed only when the manganese content of the coating is high.
2. With constant carbon and manganese contents in the coated electrode, an increase in silicon increases the percentage of Mn, Si and C, unless the Mn and C contents are high. Silicon is only $^1/_{10}$ to $^1/_2$ as active as manganese in promoting recovery of Mn, Si and C.
3. With constant silicon and manganese contents in the coated electrode, an increase in carbon decreases the percentage of carbon recovered, and improves the percentage of manganese and silicon recovered only if they are present in small amounts.

Losana's results were confirmed by Regè[42] who, however, neglected to state the relative weight of the coating, among other things. Ferromanganese (76.0 Mn, 6.91 C) was shown to be a reliable means of introducing up to 9.5% Mn into a deposit (A.C.) made by an electrode 0.16 inch diameter containing 0.10 C, 0.74 Mn, 0.015 Si. The recovery of silicon from ferrosilicon (0.32 C, 94 Si) in the coating was slight, but was improved a little by manganese. Carbon recovery was low.

A determination of the manganese, carbon and oxygen contents of metal deposited by commercial coated electrodes at different currents and voltages has been made by Okamoto,[43] but his paper was not available to the reviewers. An increase in current or voltage decreased the recovery of carbon and manganese, and increased the oxygen pick up.

Table 20—Recovery of Manganese from Coated Electrodes. Losana[12]

	Core Rod Contained 0.08 C, 0.32 Mn, 0.06 Si				Core Rod Contained 0.38 C, 0.46 Mn, 0.21 Si			
Mn, % in Coating	Total Mn in Electrode, %	% C in Weld	% Mn in Weld	Recovery of Mn, %	Total Mn in Electrode, %	% C in Weld	% Mn in Weld	Recovery of Mn, %
0	0.32	0.011	0.021	7	0.46	0.063	0.056	12
1	0.57	0.046	0.028	5	0.71	0.089	0.070	10
2	0.82	0.066	0.035	4	0.96	0.120	0.089	9
3	1.07	0.073	0.072	7	1.21	0.206	0.112	9
4	1.32	0.074	0.156	12	1.46	0.294	0.146	10
5	1.57	0.073	0.342	22	1.71	0.360	0.185	11
10	2.82	0.076	0.721	26	2.96	0.368	0.310	11
15	4.07	0.079	2.03	50	4.21	0.370	0.722	17
20	5.32	0.081	3.77	71	5.46	0.373	1.93	35
25	6.57	0.084	3.63	55	6.71	0.376	3.70	55
30	7.82	0.085	6.02	77	7.96	0.382	5.93	74
50	12.82	0.093	8.13	64	12.96	0.395	7.84	61

Table 21—Effect of Carbon in Coating on Recovery of Manganese from Coated Electrodes. Losana[12]

	Core Rod Contained 0.08 C, 0.32 Mn, 0.06 Si, 0.011, P 0.018 S					Core Rod Contained 0.10 C, 0.89 Mn 0.17 Si, 0.015 P, 0.021 S				
Carbon Content of Coating, %	Total C in Electrode, %	% C in Weld	% Mn in Weld	Recovery of C, %	Recovery of Mn, %	Total C in Electrode, %	% C in Weld	% Mn in Weld	Recovery of C, %	Recovery of Mn, %
0	0.08	0.012	0.021	15	7	0.10	0.054	0.086	54	10
1	0.33	0.020	0.034	10	11	0.35	0.091	0.102	29	11
2	0.58	0.038	0.072	12	23	0.60	0.153	0.129	22	15
3	0.83	0.075	0.105	13	33	0.85	0.196	0.146	17	16
4	1.08	0.111	0.146	14	46	1.10	0.228	0.168	15	19
5	1.33	0.135	0.168	13	53	1.35	0.228	0.184	14	21
6	1.58	0.150	0.184	12	58	1.60	0.234	0.196	12	22
8	2.08	0.18	0.203	10	64	2.10	0.251	0.213	10	24
12	3.08	0.19	0.221	7	69	3.10	0.278	0.246	8	28
16	4.08	0.20	0.240	6	75	4.10	0.290	0.302	7	34

Table 22—Recovery of Manganese from Coated Mild Steel Electrodes. Losana and Jarach[41]

No.	(Mn)	(Mn)[1]	(Si)	(Si)[1]	(C)	(C)[1]	[Mn]	100 × [Mn] / (Mn)[1]	[Si]	100 × [Si] / (Si)[1]	[C]	100 × [C] / (C)[1]	Brinell Hardness
1	3.12	1.2	0.28	0.11	2.46	0.98	0.19	16	0.01	9	0.05	5	105
2	3.02	1.2	2.94	1.2	2.34	0.93	0.26	22	0.03	3	0.07	8	107
3	2.96	1.2	5.13	2.0	2.47	0.98	0.30	25	0.14	7	0.08	8	118
4	3.10	1.2	9.92	3.9	2.36	0.94	0.42	35	0.49	13	0.10	11	136
5	2.98	1.2	17.02	6.8	2.18	0.87	0.38	32	1.93	28	0.13	15	142
6	6.43	2.6	0.48	0.19	2.30	0.91	0.41	16	0.05	26	0.07	8	108
7	6.21	2.5	2.88	1.1	2.41	0.96	0.47	19	0.27	25	0.10	10	116
8	6.34	2.5	4.97	2.0	2.18	0.87	0.50	20	0.75	38	0.13	15	140
9	6.12	2.4	8.96	3.6	2.32	0.92	0.57	24	1.27	35	0.33	36	158
10	6.30	2.5	16.94	6.7	2.29	0.91	0.55	22	2.21	33	0.40	44	170
11	12.76	5.1	0.70	0.28	2.34	0.93	1.98	39	0.09	32	0.23	25	130
12	12.12	4.8	2.86	1.1	2.16	0.86	2.34	49	0.41	37	0.29	34	164
13	12.45	5.0	5.37	2.1	2.40	0.95	2.74	55	1.17	56	0.41	43	194
14	12.02	4.8	8.92	3.5	2.20	0.87	2.62	55	2.35	67	0.40	46	188
15	12.98	5.2	17.34	6.9	2.19	0.87	2.41	46	3.18	46	0.46	53	212
16	26.45	10.5	1.28	0.51	2.32	0.92	4.12	39	0.14	27	0.41	45	248
17	25.86	10.3	2.72	1.1	2.26	0.90	4.60	45	0.45	41	0.50	56	310
18	25.31	10.1	5.12	2.0	2.18	0.87	5.80	58	1.42	71	0.54	62	328
19	25.00	9.9	9.14	3.6	2.20	0.87	5.06	51	2.82	78	0.48	55	318
20	25.32	10.1	17.02	6.8	2.30	0.91	4.42	44	3.98	59	0.49	54	308
21	3.16	1.3	2.78	1.1	4.86	1.9	0.41	32	0.06	6	0.08	4	112
22	3.05	1.2	10.46	4.2	4.78	1.9	0.71	59	1.21	29	0.18	10	138
23	3.15	1.3	17.62	7.0	4.82	1.9	0.70	54	2.65	38	0.17	9	134
24	6.34	2.5	2.80	1.1	4.90	1.9	0.88	35	0.41	16	0.12	6	126
25	6.45	2.6	10.12	4.0	4.81	1.9	0.99	38	1.76	44	0.35	18	160
26	6.72	2.7	17.26	6.9	4.76	1.9	1.08	40	3.25	47	0.39	21	164
27	12.44	5.0	2.65	1.1	4.81	1.9	2.36	47	0.61	55	0.30	16	192
28	12.20	4.9	9.98	4.0	4.62	1.8	2.68	55	2.44	61	0.39	22	190
29	12.36	4.9	17.38	6.9	4.84	1.9	2.36	48	3.92	57	0.36	19	186
30	24.10	9.6	2.69	1.1	4.76	1.9	4.58	48	0.75	68	0.49	26	324
31	23.92	9.5	10.26	4.1	4.74	1.9	4.86	51	2.90	71	0.50	26	360
32	25.76	10.2	17.44	6.9	4.82	1.9	4.12	40	5.02	73	0.28	15	208
33	3.12	1.2	2.88	1.1	9.96	4.0	0.63	53	0.25	23	0.11	3	118
34	2.96	1.2	10.36	4.1	10.21	4.1	0.89	74	1.43	35	0.19	5	130
35	2.98	1.2	17.86	7.1	10.02	4.0	0.83	69	3.10	44	0.16	4	134
36	6.41	2.5	2.60	1.0	10.34	4.1	1.09	44	0.62	62	0.20	5	132
37	6.48	2.6	11.78	4.7	9.82	3.9	1.06	41	1.88	40	0.36	9	154
38	7.00	2.8	18.03	7.1	10.40	4.1	1.12	40	3.68	52	0.32	8	150
39	12.54	5.0	2.43	0.96	9.87	3.9	2.40	48	0.70	73	0.31	8	178
40	12.40	4.9	12.24	4.9	9.84	3.9	2.70	55	3.08	63	0.31	8	186
41	12.26	4.9	17.74	7.0	9.88	3.9	2.18	45	4.06	59	0.28	7	198
42	24.98	9.9	2.68	1.1	10.06	4.0	4.39	45	0.80	73	0.49	12	342
43	24.72	9.8	11.82	4.7	9.67	3.8	4.34	44	3.78	83	0.39	10	320
44	24.80	9.8	17.58	7.0	9.94	3.9	3.92	40	5.88	84	0.23	6	280
46	5.46	2.2	2.93	1.2	2.42	0.96	0.41	19	0.25	21	0.08	8	
47	5.18	2.1	2.88	1.1	2.36	0.94	0.43	21	0.27	25	0.11	12	
48	5.38	2.1	2.81	1.1	2.40	0.95	0.45	21	0.26	24	0.14	15	
49	12.41	4.9	2.86	1.1	2.30	0.91	2.18	44	0.39	35	0.21	23	
50	12.10	4.8	2.99	1.2	2.48	0.99	2.22	46	0.43	36	0.30	30	
51	12.64	5.0	3.12	1.2	2.27	0.90	2.48	50	0.49	41	0.38	42	

Brinell hardness was measured on deposits heated 30 min. at 900° C. and furnace cooled.
( )[1] percentage of constituent calculated on basis of core rod of electrode.
( ) = weight % constituent in coating.
[ ] = weight % constituent in deposit.

	C	Si	Mn	Ca	P	S	Cu	Ni	Fe
Electrode (0.125 inch diameter)	0.11	0.042	0.42	...	0.013	0.027	trace	..	Remainder
Ferrosilicon	2.08	55.86	0.82	0.20	0.016	0.028	...	..	Remainder
Ferromanganese	1.94	3.56	79.88	0.012	0.028	0.038	...	..	Remainder
Graphite	96.83	....	...	...	...	0.21	...	..	....

The recovery of elements from coatings such as those used by Losana and Jarach probably is closely dependent on three factors: 1, thickness of coating; 2, welding conditions; 3, the other constituents in the coating, including the binder. These factors may have a controlling influence.

Pick Up

If low-manganese welding rods are deposited on higher manganese steel, the weld-metal may pick up manganese by mixing with base metal. Haardt[44] studied the diffusion of manganese from a plate of medium-manganese steel (6.3 x 4.7 x 0.79 inch, 0.1 C, 0.2 Si, 3.5 Mn) into a weld bead deposited on the surface by weaving the electrode slowly back and forth. Bare (0.07 C, trace Si, 0.4 Mn) and covered (0.07 C, 0.01 Si, 0.4 Mn) electrodes 0.16 inch diameter were used. In contrast with similar experiments on steels containing nickel, copper or silicon, Haardt was unable to secure reliable results with the manganese steel. The manganese appeared to slag at the junction of weld and base metal and to prevent diffusion of uncombined manganese. There was less diffusion of manganese than silicon, and the manganese produced an undesirable Widmannstätten structure in the weld-metal (no details).

Using a high speed steel drill 0.028–0.040 inch diame-

ter, Portevin and Leroy[45] performed a "micro-analysis" on an oxyacetylene butt weld in steel containing 0.43 C, 0.20 Si, 1.10 Mn. The weld contained 0.76 to 0.85 Mn. Hall[22] deposited pads of weld-metal, Table 23, about 1/2 inch thick on austenitic steel by means of bare electrodes. The thickness of the deposits perhaps accounts for the small pick up of manganese.

Table 23—Pick Up of Manganese by Bare Electrodes. Hall[22]

	Electrode			Deposit		
	C	Mn	Si	C	Mn	Si
Armco	0.02	0.05	0.02	0.02	0.22	0.04
High carbon	0.95	0.40	0.11	0.52	0.45	0.09
Base metal	1–1.35	12–14	0.3–0.8	..	..	..

General Observations

Suitable oxyacetylene welding rods for welding steels containing 1 to 2% Mn are Mn-V, Mn-W and Mn-Mo (no details), according to Tull.[46] Schimpke and Horn[47] recommend electrodes containing Mn, or Mo, or Ni-V for 1 to 2% Mn steels. Abrasion-resisting steel containing 0.35–0.50 C, 1.50–2.00 Mn, 0.15–0.30 Si with or without 0.2 Cu min. can be satisfactorily welded, in Wickersham's[48] experience, if high carbon steel rods are used, but stress annealing is essential.

Dobson and Taylor[49] state that there is slight air hardening near the weld in oxyacetylene welding aircraft steel containing 0.30 C max., 0.35 Si max., 1.75 Mn max., especially if the carbon and manganese are on the high side, but there is none with plain carbon steel (0.20–0.30 C, 0.60 Mn max.). Manganese in the C-Mn steel is said to produce a certain amount of grain refinement in the as-welded state. The peak hardness in the C-Mn welds is usually not over 250 Brinell, according to Sutton,[50] who showed that there was no necessity for normalizing or annealing the C-Mn steels after welding. However, Industry and Welding[51] recommended that large sections of Man-ten (0.25–0.35 C, 1 1/4–1 3/4 Mn) be preheated to 150–260° C. (300–500° F.). The same advice was given by Jennings,[3] who added that preheating prevented the hard fusion zone (no details). The sensitivity of aircraft steels (about 0.25 C, up to 1.5 Mn) to welding cracks was not affected by manganese content in Müller's[52] tests. An extensive program of research on the welding of C-Mn steels up to 0.45 C, 1.7 Mn has been announced by Jenks.[53]

In addition to having little effect on cracking, manganese in base metal had a desirable effect in decreasing porosity in arc-welded surface beads in Leitner's[54] tests. A single bead from a bare electrode (0.16 inch diameter, 150–170 amp., 17–20 volts, D.C., electrode negative, speed = 39.4 ft. per hr., 0.09 C 0.47 Mn, trace Si, 0.009 P, 0.019 S, 0.027 O_2, 0.006 N_2) on plates 0.39 inch thick and 8 x 12 inches, containing 0.07–0.12 C, 0.07–0.13 Si, 0.32–1.73 Mn. Upon being sectioned along the axis, the beads showed porosity that decreased as the manganese content of the plate increased. There was a small amount of porosity in the beads on steel containing 1.02 Mn, but none on steel containing 1.73 Mn. Llewellyn[55] quoted some tests which showed that arc-welded deposits on steel containing 0.22–0.27 C, 0.60–0.70 Mn had a better appearance and less porosity than deposits on steel containing lower manganese (no details). On the other hand, Stine[56] believed that increase in manganese, although not so dangerous as increase in Si or Al, increased the porosity of arc-welded deposits (again no experimental details). Stine stated that best arc-welding results (absence of porosity and smooth beads) were secured with steels containing not over 0.90 Mn at 0.35 C, not over 0.55 Mn at 0.25 C and not over 0.20 Mn at 0.10 C.

Manganese is often recommended as an addition to welding rods. For example, Raymond[57] describes a rod containing 0.17 C, 0.80–1.15 Mn, 0.4–0.5 Si, which is adapted to carburizing flux technique. The high carbon "flux" simply dissolves in base metal; there is no carbon gradient at the weld. The rod was discussed in the review of literature on Welding Silicon Steels. According to Kinzel,[58] the manganese favors the formation of a slag of suitable viscosity. In oxy-illuminating gas welding of mild steel, Lurie[59] found that quiet fusion and excellent slag characterized a rod containing 0.27 C, 0.53 Si, 1.29 Mn, whereas a rod containing 0.20 C, 0.47 Si, 0.46 Mn did not give good results.

Using the rods described in Table 18, Stursberg[2] observed spatter and boiling of the puddle on plates containing 0.35 C, 0.66 Mn, 0.19 Si, 0.033 P, 0.025 S, Table 24. Manganese decreased boiling and spatter at all mixture ratios. It was believed that the reaction of FeO with hydrogen or CO or iron carbide was responsible for spatter and boiling, and that Mn replaced reactive FeO by non-reactive MnO. The thickness of the slag coating on the deposit increased as the mixture ratio increased from 0.8 to 1.6 for rods 1 and 6. With rod 5 the reverse was true. Stursberg conjectured that MnO exerted a bad influence on the slag unless it was present as Mn silicate. The slag from rods with low silicon and manganese contents was viscous and surrounded each globule. As the silicon and manganese contents are increased the slag becomes less viscous and collects in globules, which may leave some of the puddle bare, if the silicon and manganese contents are too high. Contrary to Stursberg, S. W. Miller[60] found that the addition of 0.6 Mn to a low carbon oxyacetylene welding rod produced slag inclusions and laps in the deposit. The slag was difficult to float to the surface.

Table 24—Spatter and Boiling in Oxyacetylene Welding. Stursberg[2]

Rod No.	Mixture Ratio = 0.8 Boiling	Spatter	Mixture Ratio = 1.0 Boiling	Spatter	Mixture Ratio = 1.6 Boiling	Spatter
1	3+	4	1+	1	3+	3
6	2	2–	1	1	3	2+

1 = scarcely any
2 = a little
3 = moderate
4 = strong
5 = very strong

Mixture ratio is ratio of oxygen to acetylene by volume.

Although oxyacetylene welding rods for mild steel should contain 0.4–0.8 Mn, according to Bonsmann and Püngel,[61] electrodes should contain 0.8 Mn or more. Viall[19] believed that the ratio of carbon to manganese in electrodes should be 1:3. He observed a smaller amount of slag and oxide inclusions (no details) in welds made with medium manganese steel electrodes of low carbon content than with similar electrodes of high carbon content. In 1919 Escholz[62] recommended a bare electrode with 0.17 C, 5 Mn, and low content of impurities for high carbon and alloy steels. In Notvest's[63] opinion, electrodes should not contain over 0.7 Mn. He stated that overhead welding with light coated electrodes is much easier with electrodes containing 0.04–0.06 C, 0.15 Mn (straight polarity) than with electrodes containing 0.13–0.18 C, 0.40–0.60 Mn

(reversed polarity). The higher melting point of the former electrode (no details) was said to cause quicker freezing. Furthermore the former electrode was believed to have lower surface tension which permitted "the forces of cohesion to offset gravitational pull." In the third place "the negative arc stream was larger than the positive and assisted the transfer of metal." MnO in the coating forms $MnSiO_3$ so that there is no excess SiO_2 to permit the reaction: $MnS + FeSiO_3 = MnSiO_3 + FeS$, according to Notvest.

Although Paterson[64] believed that Mn in excess of 0.55% in weld-metal produces a badly pitted surface due to reactions between slag and metal, Blomberg[65] stated that the addition of 3% Mn to a neutral asbestos coating suppresses porosity in weld-metal. In 1922 Diegel[66] used powdered 50% ferromanganese as a flux in oxyacetylene welding mild steel, but the MnO particles did not form a good flux. Diegel stated that 0.4 Mn in an oxyacetylene welding rod was sufficient to combine with sulphur. Holland[67] was in favor of adding manganese to bare electrodes because Mn vapor surrounds the arc and prevents contamination of weld-metal by air. An Australian writer[68] found that the arc from an electrode containing 12 Mn, 1 C was saturated; that is, the entire end of the electrode contributes to the arc, not simply a single spot. As the manganese content was increased the arc heat was generated to a greater extent at the negative pole. Manganese was believed to steady the arc because it made the arc of low and uniform resistance.

Forge Welding

Manganese in steel has not caused forge welders much trouble. In fact, for water gas welding steel with 0.30 C, 0.20 Si, 0.06 P, 0.03 S, Diegel[69] found that 1% Mn had to be added. The MnO formed a fluid silicate with the finely dispersed particles of silica. He made three series of tests on water gas welding:

1. Steels with 0.1–0.3 C, 0.3–0.4 Mn, trace Si. Steels with over 0.15 C were sensitive to welding.
2. Steels with 0.1–0.3 C, 0.4–0.7 Mn, trace Si. These steels welded better than series 1.
3. Steels with 0.1–0.15 C, 0.6–1.0 Mn, 0.15–0.35 Si. With 0.14 C, 0.14 Si, a manganese content of 0.58% was insufficient for water gas welding. If 1.0 Mn was present, water gas welding was satisfactory. Weinrich[139] stated that boiler steel with 0.8–1.0 Mn, 0.25–0.30 Si was perfectly weldable by the water gas process.

Forge welding tests were made by Hahn[70] on steels $^3/_4$ inch diameter containing 0.1 C, 0.04 P, 0.04 S, trace Si, 0.15 Cu, with 0.63–3.41 Mn (charge analysis). Even with 3.41 Mn the forge weldability was good, although the steel picked up 0.34 C from the ferromanganese added in the ladle. The higher manganese welds were completely martensitic. In 1870, Mrázek[71] found that forge welding is improved by manganese. A steel with 0.38 C, 1.38 Mn was easy to forge weld. Roeckner[136] stated that relatively high manganese content in steel acts very well as a reducing agent to supplement the flux. Grimshaw[72] made a micrographic study of a weld made by interposing a layer of electro-deposited iron between a steel containing 0.98 C, 0.31 Si, 1.63 Mn, and another containing 0.10 C, 0.47 Si, 0.36 Mn, followed by heating to 790° C. (1450° F.). The weld was sound, and the iron had picked up carbon from the steels.

Schäfer[73] stated that it is best to have not over 0.5 Mn in steel for forge welding. The permissible manganese content decreases as the carbon content decreases (no details). Jüptner[74] also believed that Mn injures the forge welding properties of steel.

Resistance Welding

Flash welding raises the strength but lowers the ductility of rails containing 0.44–0.46 C, 1.01–1.03 Mn, 0.038–0.054 Si, 0.070–0.076 P, 0.059–0.110 S, according to Rietsch and Croskell,[75] Table 25. The rails weighed 85 lb./yd. and were of the flat bottom, bullhead type. The tensile specimens were tested in a tensometer and were, therefore, about 1 inch long, 0.1 inch diameter. The Izod fracture showed a coarser grain size in the weld than in the unaffected rail but the notch impact value was practically the same. The welded rails in static bend tests gave the same results as unwelded rails. Fish plate joints were inferior. In tup tests with a 1-ton tup, $3^1/_2$-ft. span, the welds broke when the tup was raised 4 to 6 ft.; unwelded rails withstood a drop of 10 ft. without fracture. Base metal was 185 Brinell; heat-affected zone was 210 Brinell; and weld-metal was 175 to 190 Brinell. The average and maximum widths of the heat-affected zone were $1^1/_2$ and $2^1/_2$ inches, respectively. Weld-metal had Widmannstätten structure.

Burgess and Aston[76] were able to resistance butt weld iron containing 4% Mn, but had no success with iron containing 12% Mn (no details).

Flame Cutting

Tensile and bend specimens were cut by Dümpelmann[77] from a plate 0.39 inch thick containing 0.12 C, 1.00 Mn, 0.62 Si, 0.26 Cu, 0.04 Ni, 0.00 Cr, 0.088–0.098 P, 0.024 S. The tensile specimens were 0.39, 0.79, 1.18 or 1.58 inches wide. Milled specimens had a tensile strength of 76,500 to 77,500 lb./in.^{2} parallel to the direction of rolling, and 76,500 and 78,000 lb./in.^{2} perpendicular to the direction of rolling. Illuminating gas, acetylene and hydrogen were used as preheating gases.

The detailed results showed that the yield strength (57,000 lb./in.^{2}), tensile strength, elongation (25% in 7 or 11 inches), and reduction of area (60%) were practically the same for flame cut as for the milled specimens. The width of the specimen, that is, the distance between cuts, had no effect. Bend tests on specimens 1.18 inches wide, 10 inches long cut parallel and perpendicular to the direction of rolling bent 180° in practically all cases (no details). Some cracks caused by laminations were observed. The notch impact value of standard German round notch specimens with notch on lower side of, or in, the cut surface was 6.8 to 7.4 mkg./cm.^{2} parallel to the direction of rolling, and 11.7 to 14.2 mkg./cm.^{2} perpendicular to the direction of rolling. Milled and flame cut specimens had practically the same notch impact value.

Table 25—Mechanical Properties of Flash-Welded Rail Steel. Rietsch and Croskell[75]

Location of Specimen	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, %	Reduction of Area, %	Izod Impact Value, Ft.-Lb.
Weld in center of test bar	56,000	98,500 to 104,000	12.5	27.5 to 32.5	3 to 5
Zone of finest structure	51,500 to 67,000	97,500 to 103,000	25 to 27.5	35 to 51	....
Unaffected rail	51,500 to 60,500	93,000 to 94,000	23 to 27.5	42.5 to 47.5	3 to 7

The maximum Brinell hardness (2.5 mm. ball, 187.5 kg. load) was 202 for acetylene, 219 for hydrogen and illuminating gas. Base metal was 156 Brinell. The depth of the heat-affected zone was 0.04 inch.

Manganese is easier to oxyacetylene flame cut than iron, according to Wiss.[78] The hardness of flame cut surfaces of die steel containing 3 Mn, 0.9 C, 1 inch thick was:

Manual cut, acetylene preheating flame = over 600 Brinell,
Machine cut, acetylene preheating flame = 500–530 Brinell,
Manual cut, hydrogen preheating flame = 430–460 Brinell,
Uncut base metal = 230 Brinell.

Since steel containing 0.25–0.35 C, 1.25–1.70 Mn is air hardening, Jennings[3] recommends that special precautions be taken in flame cutting it to avoid cracks. Preheating the line of the cut is advisable with heavy sections.

WELDING 14% MANGANESE STEEL

The welding of 14% Mn steel castings was the major topic of the review of literature on Welding Special Ferrous Alloy Castings. The present review summarizes information not bearing directly on castings. According to Hall (Metals Handbook, 1936 Edition, 399–404), heat treated 14% Mn steel in the rolled or forged condition has the following properties:

Proportional limit	= 40,000 to 60,000 lb./in.^{2},
Tensile strength	= 130,000 to 160,000 lb./in.^{2},
Elongation	= 60 to 70% in 2 inches,
Reduction of area	= 40 to 60%,
Brinell hardness	= 230.

The strength, hardness, and ductility are higher for forged material than for castings.

WELDING TECHNIQUE

Oxyacetylene Welding

Forged 14% Mn steel is oxyacetylene welded in the same way as castings. Less difficulty appears to be met with forged than with cast material. According to Payne,[79] Ni-Mn steel can be both arc and oxyacetylene welded, whereas plain 14% Mn steel must be arc welded. Winton[84] stated that oxyacetylene welding is inapplicable to plain 14% Mn steel because the excessive heat creates a brittle zone which fails under impact. Meslier[80] had excellent results with a filler rod of 18–8 or 25 Ni steel. Another French writer[81] preferred a rod with 23 Ni, 1.4 Cr or, less suitable, 15 Ni, 9 Cr. Very little martensite was present. Deposits of mild steel on 14% Mn steel were hard (370 Brinell) but the hardness was not uniform and the deposit was full of blowholes. According to Railway Age,[82] oxyacetylene-welded Ni-Mn steel frogs (0.6–0.9 C, 0.60–0.85 Si, 2.5–3.5 Ni, 11.0–13.5 Mn) have been in service two years without cracks. The welds were peened hot, and no effort was made to "skip about" in welding.

Extensive tests were made by Buchholz[83] on oxyacetylene welding 14% Mn steel, 0.16 and 0.39 inch thick. The filler rod contained 14% Mn. With a neutral flame or a flame containing excess oxygen the deposits were porous; it was not known whether the gas was evolved from solution or simply was emulsified. It was found that the blue cone of the flame must be as long as, or 50% longer than, the luminous tip, which indicates considerable excess acetylene. From the standpoint of slag inclusions and porosity, right-hand welding was superior to left-hand welding. Good root penetration could be obtained only if oxidation of the scarves was prevented by borax. In making X welds the first layer cracked when the reverse layer was welded because carbide precipitation occurred in the first layer. Cracks also occurred in hot peened welds and during reheating a V weld after an interruption in welding. The cracks were parallel to, and through the middle of, the weld. Cracks occurred, in general, if the welds were made rapidly and with small torches. Large torches and slow welding prevented excessive absorption of carbon and brittleness.

Metal Arc Welding

A thorough discussion of the Ni-Mn electrode has been given recently by Trissal and Winton.[84] The electrode contains 0.70–1.00 C, 0.50–1.20 Si, 3.–5. Ni, 11–15. Mn and is used bare with D.C. (reversed polarity) and coated with A.C. It will be noted that the carbon range is rather high and, indeed, it was stated that if the carbon range is 0.90–1.15 there will be an increase in hardness but the bead may crack during peening, especially in cold weather. However, a commercial electrode for 14% Mn steel contained[85] 1.3 C, 0.35 Si, 5.0 Ni, 14 Mn. According to R. P. Winton (private communication June 1938), the maximum carbon content recommended for Ni-Mn electrodes is 0.90% instead of 1.00%. An advantage of the Ni-Mn electrode is that it does not stick to base metal when the arc is struck. All defects must be cut out, yet a cutting torch should not be used unless the defective section is unusually large, in which case the heat should be restricted as much as possible to prevent carbide precipitation. If the welding current is correct, the slag will be chocolate brown; excessive current results in a black, blistered slag, no explanation being given, although blistered slag may indicate loss of C and Mn, and excessive heat which may cause hair cracks in the bead when it cools. If the metal drips from the electrode in drops, the arc is too long. Arc voltage is 30, and the current is 75–100 amp. for $^1/_8$-inch electrodes, 175–225 amp. for $^1/_4$-inch electrodes, in agreement with other writers. If porosity is to be avoided, weaving is essential. If the crater is struck with the ball peen of a machinist hammer immediately after the metal has solidified, crater cracks are prevented. Peening is preferable to filling in if it is desired to secure a smooth lap in depositing a subsequent bead. Peening also hardens the deposit to some extent. A wandering sequence is best. Davis[86] emphasizes that full generator voltage is essential with Ni-Mn electrodes.

Jennings[3] agrees with most writers that the bare Ni-Mn electrode is easier to deposit than the coated. The coating is added principally for the purpose of stabilizing the arc, the voltage of which should be 20 to 25, contrary to Trissal and Payne. Winton[84] asserts that it is impossible to maintain the arc voltage below 25–30 without extinguishing the arc as a result of the agitation of the weld-metal. In other respects Jennings agrees with Hall[87] and other authorities.

An electrode containing nickel, molybdenum and manganese with heavy extruded coating is recommended by E. W. P. Smith.[88] The covering is designed to decrease the surface tension of the puddle. Reversed polarity is used and the bead must not be quenched. The deposit is Rockwell C 5 to C 10, which is increased in service to C 46 to C 50 by cold work. The procedure to be used with bare or coated 14% Mn steel electrodes without nickel was outlined by Wanamaker,[89] Pennington[40] and Churchward,[90] but, with its water quenching of each bead, is obsolete. Nevertheless, as Brown[91] points out, hard-faced 14% Mn steel may be restored to its original ductility by being quenched from 1000° C.

MacRae[137] used a bare electrode containing 0.75 C, 3.5 Ni, 12–14 Mn for building up 14 Mn steel rails, but an electrode containing 1.0–1.25 C, 14.0–16.0 Mn for the wearing surface. If excessive grinding was found to be necessary to remove spongy metal and cracks, a low-carbon, high-nickel electrode was used as a seal to prevent spread of cracks before the high-manganese electrodes were used.

Clamping arrangements to prevent distortion in building up 14% Mn steel switch tongues by arc welding are described by Doerr.[92] Hoffmann[93] found an elongation of 0.00182 inch per inch during the filling in of the worn groove of a street railway rail with 14% Mn steel electrodes. On cooling there was a permanent contraction of 0.00011 inch per inch. Hoffmann advocated step-back welding.

The surfacing of frogs with 14% Mn and Ni-Mn electrodes was described by a railway periodical.[94] A relatively inexpensive 5% Ni steel electrode was recommended for filling deep holes. Mild steel inserts may be used instead. Before any part of the rail head cools below a red heat the deposit should be peened with a 1-lb. hammer to reduce the height 25%. If the bead is over 6 inches long cracks may be expected. According to Payne,[95] a length of 9 inches may be deposited in a single bead without cracking. Winton (private communication, June 1938) condemns the slugging of 14% Mn welds with mild steel inserts. He has observed several welded 14% Mn frogs whose failure was attributed to brittleness (6% Mn zone) in the vicinity of the inserts. Winton mentions 14% Mn steel frogs that had failed in two years due to internal defects and that had given four years additional service after being repaired with Ni-Mn electrodes. The points of new 14% Mn steel frogs may pound down as much as $^1/_4$ inch under heavy traffic in the first two months. The worn points built up with Ni-Mn electrodes did not have more than $^1/_4$-inch batter after two years. Each layer of weld-metal was peened, and trains were allowed to cold work the rough deposit before it was finish ground. Payne[96] suggests the use of inserts of Ni-Mn steel for surfacing mild steel or worn 14% Mn steel. A Ni-Mn electrode is used to weld the inserts in place. Tracy[97] describes the use of these "applicator bars" in repairing cracked 14% Mn frogs. Veeing the crack and welding was unsatisfactory. A convenient formulation of the rules to be observed in depositing Ni-Mn electrodes has been prepared by Payne[98], who points out that slag coated electrodes have the disadvantage of driving the heat into the base metal, but that a thin arc stabilizing coating is essential on A.C. electrodes. According to Tracey and Tilton,[36] the coated Ni-Mn electrode deposits a broad, shallow bead whereas the bare electrode deposit is high and narrow. The coated electrode was preferred to the bare by Hurme[99] because the coated electrode requires less current, which reduces the heat effect. The necessity for weaving the Ni-Mn electrode is accentuated by the fact that the Ni-Mn weld-metal boils to a greater extent than plain manganese steel weld-metal. *Welding Engineer*[100] states that chill cast iron can be surfaced successfully with 14% Mn steel electrodes. The deposit should be peened.

The 18–8 electrode has often been used for 14% Mn steel. For switch points Eldridge[101] recommends that the part to be surfaced be prebent $^1/_8$ to $^3/_{16}$ inch and surfaced with a few layers of 18–8 electrodes. The deposit straightens the point. Shuler[102] recommends the same procedure and believes that no metal should be deposited on 14% Mn frogs until the brittle, work hardened surface has been ground off. Llewellyn[103] describes the half-soling of 14% Mn steel dipper teeth with old truck springs and 18–8 electrodes.

Other Welding Processes

Good welds in 14% Mn steel were made by Münter[104] using the Arcogen process (combination arc and oxy-acetylene). In order to forge weld strips of steel containing 0.30 C, 12 Mn to plain carbon steel (0.25-0.30 C), Williams[105] heated the Mn steel to a dull red, and the plain carbon steel to forge welding temperature. The parts were then placed together under a steady pressure, after which a few light blows were delivered to complete the weld.

Mechanical Properties (Hardness)

The mechanical properties of welds in rolled 14% Mn steel made with a coated Ni-Mn electrode, according to Quinn,[106] are:

Tensile strength = 105,000 lb./in.^{2}
Elongation = 30%
Cold bend angle = 90° (no details)

The strength and ductility are higher than those reported by Hall for welds made with a similar electrode in cast 14% Mn steel. Csilléry and Péter[25] reported a tensile strength of 82,500 lb./in.^{2}, elongation = 9.2% in the length of the weld (no details), reduction of area = 6.0%, notch impact value = 13.3 mkg./cm.^{2} for a weld made with a bare electrode (see Table 5) in a rolled rail containing 1.00 C, 0.40 Si, 12 to 13 Mn (tensile strength = 92,000 lb./in.^{2}, elongation = 11.3% in 5 diameters, reduction of area = 23%, notch impact value = 5.9 mkg./cm.^{2} The notch impact specimen was of unusual dimensions (0.55 x 0.83 inch) with a mild notch (no details).

The hardness of the deposits tested by Zeyen[26] (see Tables 10, 17 and 19 for compositions) is shown in Table 26. The welds were lightly ground before the hardness test was made. Since the hardness of the weld-metal as deposited is not the important factor in 14% Mn steel, it is unfortunate that Zeyen did not cold work his deposits before test.

Table 26—Brinell Hardness of 14% Mn Steel Deposits. Zeyen[26]

Welding Process	Oxy-acetylene	Bare Electrode, D.C.	Lightly Coated Electrodes, D.C.	Lightly Coated Electrode, A.C.
Single bead	170	164	177	164
Three superposed beads deposited in rapid succession without cooling	177	170	174	177
Three superposed beads; each bead allowed to cool thoroughly	187	177	187	180

The hardness of the cold worked deposit was determined by Hall[108] and Rehfuss[107] (see Tables 9 and 10 for compositions), who dropped a 30 pound tup from a height of 5 feet on cones 1 inch high, 1 inch base machined from weld deposits on heat treated cast 14% Mn steel, $^5/_8$ inch thick. In some tests the cones were machined from unwelded base metal, battered to $^3/_8$ inch high and welded to form a truncated cone 1 inch high, $^1/_4$-inch top, $1^1/_8$-inch base.

The severely work hardened cones, Table 27 were 430 to 600 Brinell, the 14% Mn deposits being slightly harder than the Ni-Mn deposits. The cones did not fail in the brittle heat-affected zone. In the majority of tests the weld deposits had fine cracks after test. The 14 Mn deposit tested by Hall showed cracks radiating from the

Table 27—Brinell Hardness of Work Hardened 14% Mn Steel Deposits

No.	Specimen	Composition of Cone C	Mn	Ni	Brinell as Deposited	After 5 Blows Brinell	% Compression	After 200 Blows Brinell	% Compression	Investigator
1	Unwelded base metal	1	14	..	200	...	...	534	...	Rehfuss[107]
2	Coated 14 Mn electrode	0.75	10.0	..	240	...	23 to 33	601	...	Rehfuss[107]
3	Bare 14 Mn electrode	0.79	9.7	..	200	...	30 to 31	477	...	
4	Ni-Mn electrode	0.41	10.4	3.11	149 to 156	418 to 444	37.0 to 37.6	...	...	Hall[22]
5	14 Mn electrode	0.76	11.0	..	170 to 179	477 to 512	35.1 to 35.8	...	...	Hall[22]
6	Ni-Mn electrode	0.53*	12.7	3.09	241	352 to 429	15.2	435 to 495	38.0	Rehfuss[24]
7	14 Mn electrode	0.78*	11.4	..	220	363 to 435	17.4	477 to 495	35.8	Rehfuss[24]
8	Ni-Mn electrode	0.62*	12.6	3.25	163	387	20 to 24	430 to 444	30.8 to 36.0	Hall[23,109]

* Truncated cones.

center like spokes in a wheel; the Ni-Mn deposit had no cracks after test. These results offer little support to Horn and Tewes'[109] statement that deposits from 14 Mn electrodes are unsuitable for filling the worn grooves of trolley rails for the reason that the deposits deform too much in the early stages.

Other measurements of the hardness of as-welded deposits have been made by Portevin and Séférian[80] and Buchholz.[83] V butt oxyacetylene welds in 14 Mn steel[80] made with a 14 Mn rod were 260 Brinell in the lower part of the weld, 220 in the middle. Oxyacetylene welds made with 18–8 rod (0.12 C, 0.63 Mn, 0.66 Si, 17 Cr, 9.25 Ni) were 265 max. in the lower part, 250 in the middle (4.40% Mn). Arc welds made with a bare electrode were softer: 200 Brinell, lower part (4% Mn); 175 in the upper part (2% Mn). Oxyacetylene welds made with a rod containing 0.60 C, 22.90 Ni, 1.08 Mn, 1.40 Cr were 175 Brinell max. (5% Mn) at the junction of weld with base metal. Similar welds with a rod containing 0.26 C, 0.28 Mn, 14.50 Ni, 0.10 Cr were 215 Brinell in the upper part (6% Mn), 185 in the middle and 175 in the upper part. In all specimens the maximum hardness occurred in the weld-metal. The hardness of base metal (165 Brinell, 0.39 inch thick) was uniform to the edge of the weld. In Buchholz's[83] tests, oxyacetylene welds in 14 Mn steel (195 to 231 Brinell) made with a reducing flame and 14 Mn rod had a Brinell hardness of 184 to 190, exactly opposite to the results of Portevin and Séférian.

The hardness of an oxyacetylene butt weld in 14 Mn steel, 0.16 inch thick made by Portevin and Séférian[80] with a mild steel rod (0.05 C, 0.31 Mn, trace Si) was 400–420 Brinell, the weld-metal containing 7% Mn. The weld-metal had a martensitic structure, and islands of mild steel were found that had solidified before absorbing manganese and, consequently, retained an overheated, pearlitic structure.

Microstructure

The microstructural peculiarities of welds in cast 14% Mn steel were discussed in the review of literature on Welding Special Ferrous Alloy Castings. Welds in heat treated wrought 14% Mn steel are subject to the same microstructural changes as in the cast steel. The deposits examined by Rehfuss[107] and Zeyen[26] consisted of coarse columnar grains with dendritic markings and a small amount of free carbide. The lower layers of 14% Mn weld-metal in Csilléry and Péter's[25] deposits were coarser grained than the upper. Fine, intercrystalline cracks were observed in the heat-affected zone, which were said to be caused by the high thermal gradient in the weld, which, in turn, was related to the low thermal conductivity of 14% Mn steel. A hot-peened weld contained slip bands in the lower layers.

In their study of butt welds in 14 Mn steel 0.39 inch thick, Portevin and Séférian[80] found that the grain size of the heat-affected zone of oxyacetylene welds increased to $S/S_0 = 19$ (S = average plane area of each grain at the section considered; S_0 = average plane area of each grain of unaffected base metal) at the fusion line to $S/S_0 = 14$ at a distance of $^1/_2$ inch from the fusion line. The limit of the zone of coarsened grains was $^3/_4$ inch from the fusion line. In arc welds, presumably multilayer, the grain size commenced to increase $^1/_4$ inch from the fusion line, increased to $S/S_0 = 13$ at a distance of $^1/_8$ inch from the fusion line, and decreased to $S/S_0 = 2$ at the fusion line. The fine grained area at the fusion line was not explained. The welds were made with an 18–8 rod.

No carbides were detected (alkaline $KMnO_4$ etch) by Portevin and Séférian[80] in oxyacetylene welds in 14 Mn steel, 0.16 inch thick, made with a 14 Mn rod. The dendritic appearance of the weld was created by martensitic areas, probably representing segregation. Since the coefficient of expansion (0–300° C.) of the rod was 21.50×10^{-6} and that of the weld-metal was 18.41×10^{-6}, it was deduced that 25% of the weld-metal was martensite, the remainder austenite.

According to Jennings,[3] the presence of nickel in the Ni-Mn electrode results in a transition zone between deposit and base metal (no details). If the carbon content of the electrode is held as low as possible, the carbon content of the transition zone is diluted, so that carbide precipitation is reduced to a minimum (no details).

The microstructure of welds between 14% Mn steel and other steels may involve transition zones in which a change of phase occurs as well as a change in concentration. Rapatz and Hummitzsch[110] found that the martensitic transition zone between mild steel and 14 Mn weld-metal is wide and brittle. There was a sharp line of demarcation between the martensite and the ferritic mild steel in the etched section, but the martensite merged gradually into the austenite of the 14 Mn deposit. Water quenched from 1000° C. the martensitic structure of the mild steel merged gradually into the martensitic transition zone of weld-metal; there was a jagged line of demarcation between the austenitic structure of the weld-metal and the martensitic transition zone. The sharp line of demarcation between mild steel and weld-metal in the as-welded state, therefore, is not an indication of lack of junction but rather is an etching effect. The wider transition zone with manganese austenite (12–14 Mn, 1.2 C, or 0.16 C, 17.7 Mn, 5.4 Ni) than with nickel austenite (0.12 C, 28 Ni, 3 Cr) was said to be due to the more rapid diffusion of manganese in mild steel. Manganese-nickel austenite did not penetrate along the grain boundaries of plain carbon steel (0.50 C) as much as nickel austenite. There was no penetration of 14 Mn manganese steel along the grain boundaries of low-

carbon steel containing 0.12 C. On the other hand, weld metal containing 0.12 C, 28 Ni, 3 Cr penetrated deeply along the grain boundaries of 14% Mn steel (1.2 C, 12–14 Mn). Manganese austenite has a higher coefficient of thermal expansion than nickel austenite. Consequently, the 14 Mn or Ni-Mn weld-metal usually has shrinkage cracks in welds with higher carbon steels. Manganese austenite was believed to be more sensitive to overheating (no details) than nickel austenite.

From the standpoint of microstructure, Portevin and Séférian[80] found that the pick up of manganese by the weld-metal is the determining factor in depositing mild steel on 14 Mn steel or 14 Mn steel on mild steel. In the former instance the weld-metal was martensitic (number of layers and type of welding not stated) and attained 370 Brinell in the lower part, 350 Brinell in the upper part farthest from the base metal. Unfortunately, the deposit was porous. If 14 Mn steel was deposited on mild steel (110 Brinell) a thin layer of martensite (400 Brinell) was formed at the fusion lines, as other investigators have observed.

In contrast with Rapatz and Hummitzsch, Hurme[39] observed a band of martensite in the zone of low-carbon steel into which carbon had diffused from 14% Mn steel weld-metal. There was no troostite or sorbite. Hoffmann's[27] micrograph showed complete junction of 14 Mn steel weld-metal with mild steel, and Czako[111] showed a micrographically perfect junction in a pressure weld between high speed steel and a steel containing 12% Mn. Interesting micrographs of oxyacetylene welds in 14 Mn steel, 0.16 inch thick, are to be found in a paper by Portevin and Séférian[80], who employed the rods described in the section of Hardness. All the welds were dendritic, and junction was perfect. Martensite was said to be present to the extent of 15 to 20% in the fusion zone of the 18–8 and 15 Ni—10 Cr welds. The evidence for martensite was based on determination of the coefficient of expansion of weld metal, but no allowance seems to have been made for the pick up of manganese by the deposited metal. No martensite was found in the 23% Ni weld.

Flame Cutting

There is no difficulty in oxyacetylene flame cutting 14% Mn steel, according to Wiss.[78, 112] Manual cut surfaces, however, are coated with ledeburite (high carbon brittle eutectic), which sensitizes the surface to cracks. No ledeburite was observed on machine cut surfaces, the hardness of which was 320 Brinell (base metal = 220 Brinell). The increase in hardness in the machine cuts was ascribed to a thin layer of martensite on the surface. Beyond the martensitic zone was a zone in which carbide precipitation had occurred in the austenite. The heat-affected zone in flame cut 14% Mn steel is not so deep as in mild steel because the thermal conductivity of the 14 Mn steel is low. If the cutting torch is followed by a stream of water, the edge remains austenitic but nevertheless, carbide precipitation occurs in the grain boundaries. Therefore, Wiss believed that flame cut 14 Mn steel should be heat treated.

Trissal[84] stated that 14% Mn steel melts but does not burn (no sparkling) during flame cutting. Yet he stated that the flame cut surface must be ground in order to remove oxidized metal or ledeburite. As little heat as possible should be used to minimize carbide precipitation. According to Davis,[113] a higher oxygen pressure than usual is necessary in flame cutting 14 Mn steel, but if an excessive amount of oxygen is used it cools the cut, the slag freezes, and cutting ceases, according to R. P. Winton (private communication, June 1938).

WELDING NICKEL-MANGANESE STEELS

The recovery of nickel and manganese from the coating of a mild steel electrode was studied by Losana and Jarach[41] (see Table 24 of the review of literature on Welding Nickel Steels, American Welding Society Journal, **17** (5) Suppl. 1–17, May 1938). The recovery of manganese was low. Portevin[114] mentioned that an oxyacetylene welding rod containing 0.10–0.20 C, 1.3 Mn, 0.4–0.9 Ni was used to some extent in Austria.

The welding and flame cutting of steel $^1/_8$ to $^3/_8$ inch thick containing 0.25–0.40 C, 10–12 Ni, 6–8 Mn to itself and to mild steel for transformer covers are described by Orr.[115] Heavy coated 18–8 electrodes are used with 10 to 15% higher current than for mild steel electrodes. The electrode should contain 17–19 Cr, 7.50–10 Ni, 0.06–0.15 C. The welded joints were as strong as or stronger than mild steel and had better ductility. There was no difficulty in flame cutting.

WELDING COPPER-MANGANESE STEELS

Butt welds in steel containing 0.25 C, 1.35 Mn, 0.53 Cu (86–88 B Rockwell) made with a coated low-carbon electrode have a tensile strength of 82,850 lb./in.^{2}, free-bend elongation = 40.4% and 88–90 B Rockwell, according to Jennings.[116] Welds made with a coated low-molybdenum electrode have 86,020 lb./in.^{2} tensile strength, 51.2% free-bend elongation, and 86–92 B Rockwell. The welding procedure is the same as for mild steel, the best welding properties being obtained with 0.25 C or slightly less, and with the manganese content nearer 1.25 than 1.75%.

Table 28—Pulsating Tension Fatigue Strength of Welded Mn-Cu Steel. Weiss and Hovel[117]

Unwelded Steel	C	Mn	Si	P	S	Cu	Ni	N_2	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, %
U	0.19	1.02	0.32	0.031	0.022	0.51	0.03	0.008	51,600	80,200	23.0
H	0.20	1.20	0.43	0.042	0.029	0.27	0.07	0.008	51,200	78,700	24.5
P	0.16	1.11	0.56	0.035	0.030	0.38	0.05	...*	56,700	76,100	20.8

* 0.02 Cr.

Weld	Pulsating Tension Fatigue Limit, Lb./In.^{2}	Weld	Pulsating Tension Fatigue Limit, Lb./In.^{2}
U to U	38,400	U to H	35,600
H to H	32,700	U to P	37,000
P to P	34,100	P to H	34,100

Table 29—Oxyacetylene Welds with a Cu-Mn-Ni Rod, Czternasty[1]

Specimen	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Cold Bend Test* Angle, Degrees	Cold Bend Test* Elongation, %	Quench Bend Test* Angle, Degrees	Quench Bend Test* Elongation, %	Notch Impact Value, Mkg./Cm.²	Yield Strength, Lb./In.², at Elevated Temperature, 300° C.	Yield Strength, Lb./In.², at Elevated Temperature, 400° C.
Unwelded base metal	39,200	63,500	...	..	180	..	19.4	27,000	20,000
As welded	41,500	69,000	180	34	180	33	6.7	32,700	24,200
Normalized*	40,800	65,000	180	30	180	38	10.7	31,300	22,800
Hot forged*	39,400	63,500	180	30	180	35	10.4	28,500	22,000

* No details.

Composition of Plate, Rod and Weld

	C	Mn	Si	Ni	Cr	Cu	P	S
Plate	0.12	0.80	0.24	..	..	..	0.029	0.026
Rod	0.14	1.00	0.40	0.80	0.10	0.40	0.011	0.006
Weld	0.11	0.74	0.25	0.73	0.10	0.38	0.020	0.009

The pulsating tension fatigue strength of X welds made by the same welder with the same electrode (no details) in three steels 0.47 inch thick, Table 28, was determined by Weiss and Hövel.[117] The base metals had a pronounced banded structure, especially steel P. The specimens were 1.58 to 1.97 inches wide and were machined on all sides. The coarse grain structure created by the last layer was not completely removed. Specimens without X-ray defects were used. The lower tensile load was 1400 lb./in.² in all tests, which were at 11 cycles/sec. and based on a criterion of 2 million cycles.

The fatigue strengths vary slightly in accordance with the tensile strengths. About half of the fatigue failures occurred in the weld. An unmachined weld in U steel had a fatigue strength of 14,200 to 20,000 lb./in.², fracture occurring at the junction of weld with plate. Poor root penetration not revealed by X-ray but shown in microsections caused a machined weld in P steel to fail after only 32,000 cycles at an upper tensile stress of 34,100 lb./in.²

Static tension tests of arc-welded oil well casing (7 inches o.d., 0.34-inch wall, 0.23–0.24 C, 1.31–1.35 Mn, 1.14–1.15 Cu, 0.01 Si, 0.034 S, 0.025 P, yield strength = 81,400 lb./in.², tensile strength = 109,000 lb./in.², elongation = 27% in 2 inches) by Hodell[7] showed that the joint efficiency based on the tensile strength of the heat-treated casing steel was 76 to 84%. The joints were butt welded with three beads of covered electrode ($^3/_{16}$ inch diameter), the weld-metal of which had a tensile strength of 100,000 lb./in.² Fracture occurred through weld and pipe. The heat of welding reduced the strength of the casing but not to the extent indicated by tests in which samples of the casing were heated 15 min. at 650° C. and cooled in air. These tests revealed that the strength was reduced to 80% of heat-treated value, yet the welded casings had efficiencies up to 84%. Since the heat-affected zone during welding does not remain at 650° C. as long as 15 minutes, the time of heating affects the loss in strength. The static tensile strength of a butt-welded joint similar to the above in casing containing 0.20 C, 1.20 Mn, 0.48 Cu, 0.02 Si (80,000 lb./in.², tensile strength unwelded) was 77,000 lb./in.², fracture occurring through the weld.

WELDING CU-MN-NI STEELS

Oxyacetylene double V butt welds were made by Czternasty[1] in a steel 0.59 inch thick, Table 29, using a Cu-Mn-Ni steel rod. The recovery of Cu and Ni was nearly complete, and the recovery of Mn was rather high. The weld had higher strength than base metal, but the notch impact value was low. Normalizing raised the notch impact value and, to a large extent removed the Widmannstätten structure in the weld. Hammering at a red heat improved the grain size and pearlite distribution, but did not improve the mechanical properties, because the low-alloy manganese steels are said to be difficult to forge and tend to crack.

WELDING CU-MN-CR STEELS

Some results summarized in the section on Welding Chromium-Copper Steels in the review of literature on Welding Chromium Steels showed that low-alloy steels containing Cu, Mn and Cr have good welding properties. Meunier and Rosenthal[118] deposited 1 or 4 beads of a plain carbon electrode, 180 amp. at a speed of 7.1 inches per minute on the surface of a steel 0.39 inch thick containing 0.22 C, 1.03 Mn, 0.34 Si, 0.27 Cr, 0.55 Cu, Table 30. The bead on the bend specimen was machined flush. The notch impact specimen was of Mesnager type with the notch through the bead into the heat-affected zone. The results indicated that the Cu-Mn-Cr steel had less ductility and notch toughness in the welded condition than welded Cu-Cr-Mo steels of the same carbon content.

Table 30—Mechanical Properties of Surface Welded Cu-Mn-Cr Steel. Meunier and Rosenthal[118]

Specimen	Bend Angle, Degrees	Bend Elongation, %	Notch Impact Value, Mkg./Cm.²	Maximum Brinell Hardness
Unwelded	180	45	10	180
1 layer	90	19	8.7	260
4 superposed layers	180	33	10.5	195

Face bend and impact tests were made by Sikkema[119] on V butt welds made with a shielded arc electrode in low alloy steel 0.39 inch thick containing 0.13 C, 0.37 Si, 1.08 Mn, 0.43 Cr, 0.57 Cu. The bend specimens were machined to 2.4 inches wide, 0.26 inch thick, the plunger was 1.0 inch diameter, the rollers were $2^3/_4$ inches diameter, and their centers were $5^1/_2$ inches apart. No cracks appeared in specimens bent 180° (not flat). The notch impact value (Mesnager specimen) was 13.2 mkg./cm.² unwelded, and 7.1 to 11.8 welded. Unmachined unnotched impact specimens were gripped at the junction of weld and base metal. The impact value was 7.1 to 7.6 mkg./cm.², but most of the unnotched specimens failed to break. A maximum hardness of 86 B Rockwell was observed in the heat-affected zone of butt and fillet welds in plate 0.39 inch thick.

Comparing a number of steels containing about 0.20

Table 31—Composition and Hardness of Plates and Weld Metals Used by Quadflieg[120]

	Composition of Plate or Weld-Metal							Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 5 Diam.	Reduction of Area, %
	C	Mn	Si	P	S	Cu	Cr				
Low-Alloy Steel A	0.18	1.01	0.40	0.05	0.02	0.58	0.42	51,500	83,500	28.0	52
Low-Alloy Steel B	0.15	1.04	0.56	0.04	0.02	0.41	0.15	54,500	84,000	28.1	53
						N_2	O_2				
Electrode 4 for Steel B	0.09	0.48	0.18	0.043	0.05	0.032	0.109	....	....	..	..
Electrode 5 for Steel B	0.15	0.79	0.09	0.06	0.034	0.017	0.094	....	....	..	..
Electrode 6 for Steel A	0.11	0.85	0.05	0.046	0.043	0.024	n.d.	....	....	..	..

Brinell Hardness* of Welds

Specimen Welded With	As-Welded				Heated to 850° C. Slowly Cooled				Heated to 850° C. Rapidly Cooled				Water-Quenched from 960° C., Drawn at 600° C.			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Electrode 4	150	180	170	150	130	120	115	110	130	120	115	110	240	230	170	150
Electrode 5	160	180	180	160	150	150	140	140	150	150	145	140	...	...	...	...
Electrode 6	160	200	190	165	140	140	135	130	...	...	...	...	...	...	...	...

* Converted from Rockwell B.
1 = base metal; plate A was 0.41 inch thick; plate B was 0.47 inch thick.
2 = heat-affected zone.
3 = junction of weld and base metal.
4 = weld-metal.

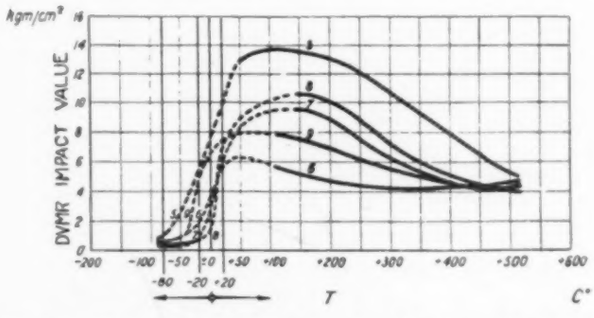

Fig. 1—Notch Impact Value (Mesnager, kgm./cm.²) as a Function of Temperature of Test for Plate B Welded with Electrode 4 in Table 29

Curve 5—unwelded base metal
Curve 6—as-welded
Curve 7—weld heated to 850° C., slowly cooled
Curve 8—weld heated to 850° C., rapidly cooled
Curve 9—weld quenched in water from 850° C., drawn at 600° C.
Quadflieg[120]

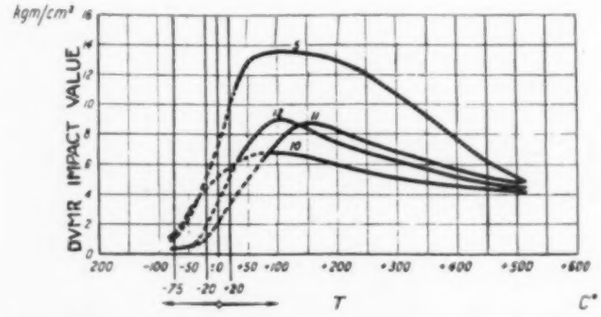

Fig. 2—Notch Impact Value (Mesnager, kgm./cm.²) as a Function of Temperature of Test for Plate B Welded with Electrode 5 in Table 29

Curve 5—unwelded base metal
Curve 10—as-welded
Curve 11—weld heated to 850° C., slowly cooled
Curve 12—welded heated to 850° C., rapidly cooled
Quadflieg[120]

C, 0.5 Si, 1.1 Mn, 0.4 Cu, 1.18 and 2 inches thick, upon which a bead from a covered electrode 0.20 inch diameter had been deposited, Bierett[135] found that steels without chromium had maximum Vickers hardness of 260–290 in the heat-affected zone, whereas a steel with 0.4 Cr (0.20 C, 0.38 Si, 1.04 Mn, 0.41 Cu, 0.38 Cr) had 430 Vickers Hardness. In a bend test with the bead in tension, the steel containing chromium failed at 5° (2 inches thick, 5% elongation in 0.39 inch). The steels without chromium failed at 20° bend angle (10 to 20% elongation in 0.39 inch).

Notch impact tests (16 ft./sec.) were made by Quadflieg[120] on standard German round notch specimens machined from V butt welds, Table 31. The notch was in the root of the weld. The results, Figs. 1 to 3, show that the base metal has higher notch impact value than the welds, especially above 20° C.

With electrode 4 on plate B, Fig. 1, normalizing improved the impact value. A slag inclusion in the middle of the fractured section generally raised the impact value 0.5 to 1.0 mkg./cm.² at all temperature, but if the slag inclusion was at the base of the notch the impact value, normalized or as-welded, was reduced as much as 3 mkg./cm.² Quadflieg was unable to offer a sound explanation. Water quenching followed, by drawing, lowered the temperature of the transition zone by 30° C.

With electrode 5 on plate B, Fig. 2, normalizing raised the impact value at +50 to +500° C. but lowered the impact value at −100 to +25° C. Annealing above Ac_3 lowered the impact value of welds with electrode 6 in plate A, Fig. 3, to zero below −20° C. The as-welded specimens had higher notch impact value than unwelded base metal at low temperatures.

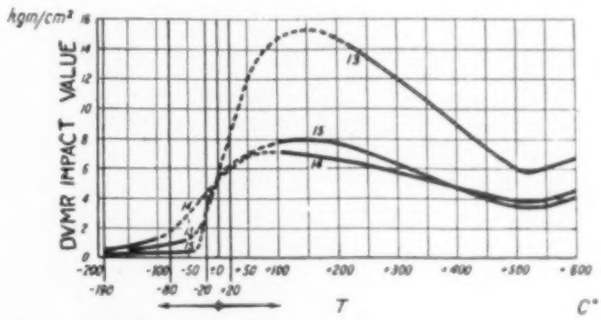

Fig. 3—Notch Impact Value (Mesnager, kgm./cm.²) as a Function of Temperature of Test for Plate A Welded with Electrode 6 in Table 29

Curve 13—unwelded base metal, 0.40 inch thick
Curve 14—as-welded
Curve 15—weld heated just below A_1, cooled slowly
Quadflieg[120]

Small welds deposited at low currents were found by R. Smallman-Tew, (private communication, June 1938) to be the cause of excessive hardness in the heat-affected zone and cracking in steel containing 0.26 C, 0.70 Mn, 0.11 Si, 0.9 Cr, 0.3 Cu. Conditions are given in Table 32 for depositing $^3/_{16}$-inch fillet welds so that the maximum hardness in the heat-affected zone is not over 300 Brinell and the structure is satisfactory (sorbitic).

Table 32—Conditions for Arc Welding Cr-Cu-Mn Steel Without Cracks. R. Smallman-Tew

Thickness of Plate, Inch	Diameter of Covered Electrode, Inch		
	0.128	0.160	0.192
$^1/_4$	90 to 100 amp.	120 to 135 amp.	.....
$^3/_8$	110 to 120 amp.	115 to 130 amp.	130 to 150 amp.
$^1/_2$	not recommended	135 to 150 amp.	150 to 175 amp.

Hardness and Structure of Heat-Affected Zone of Cr-Cu-Mn Steel After Welding with Covered Electrode, 0.160 Inch Diameter

Plate Thickness, Inch	Current, Amp.	Brinell Hardness	Structure
$^1/_2$	110	400	Martensitic
$^1/_2$	135	250	Sorbitic
1	135	490	Martensitic, cracked

The shrinkage stresses in patches welded into $^7/_8$-inch plates containing 0.15 C, 0.50 Si, 1.05 Mn, 0.34 Cr, 0.60 Cu with covered electrodes have been measured by Gerold and Müller-Stock.[121]

WELDING CU-SI-MN STEELS

Oxyacetylene butt welds were made by Holler and Frankenbusch[122] in a steel 0.39 inch thick containing 0.18 C, 0.60 Si, 0.40 Cu, 1.3 Mn. The welds were equal in strength to base metal, Table 33, regardless of heat treatment. The rod contained very little carbon but had some Ni, Mn and Cu (no details). The tensile specimens were 1 inch parallel section, 0.79 inch wide, fillet radius = 0.59 inch; fractures occurred outside the weld. Standard German plunger bend specimens were used. The notch in the DVMR impact specimen was in the root of the weld. The notch impact values were entirely satisfactory. The coarse grain structure of the as-welded specimens was refined by the reverse weld and peening.

Table 33—Oxyacetylene Butt Welds in Cu-Si-Mn Steel. Holler and Frankenbusch[122]

Specimen	Tensile Strength, Lb./In.^{2}	DVMR Notch Impact Value Mkg./Cm.^{2}	Bend Angle, Degrees
Unwelded base metal	77,000 to 78,000	6.9 to 7.6	...
As-welded	82,500 to 89,500	7.4 to 8.3	80 to 90
Welded and annealed at 900° C.	81,000 to 82,500	.....	...
Welded and reverse welded	81,000 to 81,500	8.7 to 9.6	180
Welded and peened	82,000 to 83,000	8.2 to 9.3	180

Unmachined, multi-layer butt welds made with covered electrodes and backing strip in cross-shaped reinforcing bars (cross-sectional area = 2.7 sq. in., 0.22 C, 0.9 Si, 0.5 Mn, 0.5 Cu), according to Brebera,[123] Table 34, had about the same properties as unwelded bars. The microstructure was fine grained.

Table 34—Tensile and Bend Properties of Cu-Si-Mn Reinforcing Bars. Brebera[123]

Specimen	Elastic Limit, Lb./In.^{2}	Tensile Strength, Lb./In.	Elongation,* % in 10 Diam.	Reduction of Area, %	Bend Test, 5 or 6 Diameters: Angle, Degrees	Bend Test, 5 or 6 Diameters: Surface Elongation
Unwelded	59,500	83,500	22.6	53.7	...	...
Welded	57,000	81,500	26.1	47.9	180	10.3

* Diameter of circle circumscribed about section = $2^3/_8$ inches.

Thousands of arc-welded tension, bend and notch impact specimens were tested by Stieler[124] in a low-alloy steel containing 0.15 C, 0.70 Si, 0.90 Mn, 0.35 Cu. In the complete absence of welding details the results can not be interpreted. Stieler did not favor the addition of silicon to low-alloy structural steels (minimum tensile strength = 74,000 lb./in.^{2}) because silicon favors cracks in fillet welds.

WELDING CU-SI-MN-MO STEELS

Tests were made by Dümpelmann[125] on flame cut steel 0.39 inch thick containing 0.13 C, 1.00 Mn, 0.60 Si, 0.42 Cu, 0.1 Mo. The tests and test results were practically identical with those obtained on flame cut steel containing 0.12 C, 1.00 Mn, 0.62 Si, 0.26 Cu, described in the section on Flame Cutting Pearlitic Manganese Steels. The distance between cut surfaces (0.39 to 1.6 inches) had no effect on tensile strength, elongation or reduction of area. Unaffected base metal was 180 to 187 Brinell. The maximum Brinell hardness (2.5 mm. ball, 187.5 kg. load) of the cut surface was 211 for oxyacetylene cuts, 219 for oxyhydrogen cuts and 202 for oxy-illuminating gas cuts.

WELDING CR-MN-SI STEELS

As with most low-alloy structural steels, the mechanical and welding properties of Cr-Mn-Si Steel depends on

Table 35—Mechanical Properties of Welded Cromansil Steels[4]

Steel	Process	C	Mn	Si	Cr	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, % in 2 In.	Reduction of Area, %	Charpy Impact Value, Ft./Lb.
Low carbon, unwelded	....	0.13	1.32	0.78	0.43	60,000	82,000	43	..	28
Low carbon, welded	Oxyacetylene	0.13	1.32	0.78	0.43	59,000	86,000	17	..	31
Higher carbon, unwelded	....	0.18 to 0.23	1.10 to 1.40	0.65 to 0.85	0.40 to 0.60	55,000	88,000	15*	..	..
Higher carbon, welded	Covered electrodes**	0.18 to 0.23	1.10 to 1.40	0.65 to 0.85	0.40 to 0.60	....	....	8 to 31	16 to 44	27 to 35

* In 8 inches.
** Various brands.

Table 36—Typical Tensile Properties of Arc-Welded Cromansil. Jennings[3]

(The Steel Contained 0.20 C, 1.04 Mn, 0.51 Cr, 0.91 Si)

	Electrode	Heat Treatment	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 Inches
Unwelded		As-rolled	55,000 to 60,000	80,000 to 90,000	20 to 28
Welded	Plain low carbon	None	45,000	78,000	24
Welded	Plain low carbon	Annealed 650° C.	42,000	75,000	26
Welded	Molybdenum alloy	None	60,000	91,000	22
Welded	Molybdenum alloy	Annealed 650° C.	56,000	88,000	26

the carbon content. For example, the Committee on Low Alloy Steels,[4] Table 35, lists the low-carbon steel as "foolproof" and the higher carbon steel as moderately air hardening under average welding conditions. Unfortunately, the thickness of the plate and details of welding are not given. The maximum local hardness of the low-carbon joint was not over 96B Rockwell; the hardness of the higher carbon joint was not stated. The lower carbon joint fractured in base metal; the location of fracture in the higher carbon specimens was not reported. The Committee did not intend to imply that only oxyacetylene welds were foolproof in the lower carbon steel, nor that only arc welds led to air hardening in the higher carbon steel. There was only a limited number of test results available.

If an unalloyed low-carbon electrode is used to weld Cr-Mn-Si steel, according to Jennings,[3] Table 36, the welds are not so strong as base metal. It is surprising that the lowest ductility in the welds listed in Table 29 was obtained with a molybdenum alloy electrode. Yet Jennings obtained high ductility with these electrodes and, in fact, recommends them.

Theisinger[126] used the technique described in the review of literature on Welding Chromium Steels (section on Cr-Mo Steels) to determine the effect of speed on the hardness of the heat-affected zone in steel containing 0.13 C, 0.42 Cr, 1.20 Mn, 0.72 Si. Upon automatically depositing a single bead of bare electrode weld-metal (375 amp.). At 12 inches per minute and slower the maximum increase in hardness of the heat-affected zone compared with unaffected base metal was less than 100 Brinell units. At 18 inches per minute the maximum hardness in the heat-affected zone was 293 Vickers hardness, the unaffected steel being 180 Vickers hardness. Even at 18 inches per minute the heat-affected zone was said to consist of fine grained sorbite. It was said that a little preheating reduced the maximum increase below 100 Brinell at 18 inches per minute.

The welding characteristics of Cr-Mn-Si structural steels are similar to Cr-Cu steels, according to Kinzel and Crafts[127] (see review of literature on Welding Chromium Steels; section on Cr-Cu Steels). Up to 0.15 C, Harris[128] stated, the Cromansil steels have no air hardening tendencies. Butt welds in lower carbon Cromansil had a yield strength = 63,000 lb./in.², tensile strength = 86,000 to 98,000 lb./in.², bend elongation = 20 to 35%. Effective coatings to preserve the alloying elements in Cromansil electrodes consist of a purely mineral slag; calcium iron silicate, which has a low melting point.

Steel[129] described arc-welded subway car truck frames of Cromansil. The carbon content was not over 0.17% and the frames were heat treated after welding to avoid trouble in service repairs. Schimpke and Horn[47] believed that Si-Mn-Cr boiler steel must be normalized at 830° C. immediately after welding. Arc welded drag line buckets were successfully fabricated by Gibson[130] in a steel containing 0.21 C, 0.55 Cr, 1.29 Mn, 0.76 Si. Welded Cromansil platforms (0.15–0.25 C, 0.40-0.60 Cr, 1.10–1.40 Mn, 0.60–0.90 Si) were used in the Burlington streamlined trains.[131] Cromansil (0.17–0.23 C) was also recommended by Charlton[132] for welded railway underframes.

Instructions for oxyacetylene welding Cromansil steels are given by Westin,[133] Table 37. Smaller tips are recommended for steel with over 0.25 C than with less than 0.25 C. A high-test (Si-Mn) rod is used up to 1/4 inches for thicker plate a Mn-Mo rod is best. Backhand welding and beveled scarves are used with plate 3/16 inch thick and over. Forehand welding is used for sheet. *Industry and Welding*[134] are in general agreement with Westin, but recommend a Cromansil rod. If the steel contains over 0.25 C, the welds should be normalized at 900° C. In arc welding no bevel is necessary up to a thickness of 1/8 inch. From 1/8 to 1/2 inch thick, a 60° V is used; a U joint is used above 1/2 inch.

Table 37—Oxyacetylene Welding Cromansil. Westin[133]

Plate Thickness, Inch	Rod Diameter, Inch	Tip Size	Oxygen Pressure, Lb./In.²	Bevel
1/16	1/16	4	10	none
1/4	3/16	8	19	90°
1/2	5/16	12	30	70°

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L. A. Davis, L. A. Davis Welding Supplies, Wilkes-Barre, Pa.

B. H. Payne, Stulz-Sickles Company

R. Smallman-Tew, London, England

J. M. Trissal, Illinois Central System

R. P. Winton, Norfolk & Western Railway Company.

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SUGGESTED RESEARCH PROBLEMS

1. The effect of preheating (300–500° F.) on the weld quench values (Bruckner Method) of low-alloy manganese steels.

2. For a given set of welding conditions how does the permissible manganese content of base metal vary with the contents of carbon and other alloying elements?

3. The loss of manganese in fusion welding is commonly attributed to oxidation. Quantitative tests of the amount of Mn lost by vaporization and by oxidation (nature of oxidation product) in welding different manganese steels by different processes would aid in explaining the cause of manganese loss. The effect of other elements on Mn recovery should be studied. A related problem is the possibility that vaporization of Mn may increase the difficulty of spot welding steels with high manganese content.

4. The welding properties of steels with 0.2 C, 2 to 5 Mn and the mechanical properties and structure of welds made therein by different processes.

5. What are the consequences in welding of the well-known effect of manganese in increasing the sensitivity of steel to overheating?

6. Is there a similarity between the Mn-Al-S balance in cast steel, which governs ductility, and the similar balance which may obtain with aluminum dioxidized weld-metal?

7. At the end of the section on General Observations it is stated that manganese up to 12% exerts a large influence on the characteristics of the arc. A quantitative study of the effect of manganese on the arc is called for.

8. What are the causes of crater cracks in arc welding 14% Mn steel? In what way does peening prevent the cracks?

9. To what extent is it true that the relative absence of brittleness in the heat-affected zone of welds in 14% Mn steel made with Ni-Mn filler rods is due to the diffusion of nickel into the heat-affected zone?

TENSILE IMPACT TESTS ON WELDS at Low Temperatures*

By OTTO H. HENRY†

THESE investigations are a continuation of the work started several years ago at the Polytechnic Institute of Brooklyn on a study of the behavior of welded joints under tensile impact at low temperatures. For a description of the apparatus and methods used the reader is referred to two earlier papers by the author: "Static Impact Tensile Properties of Some Welds at Ordinary and Low Temperatures" October 1937 *Research Supplement*, pp. 41–46; and "The Effect of Low Temperature on the Tensile Impact Resistance of Iron, Steel and Welded Joints," *Research Supplement*, October 1936, pp. 2–9.

The size of the specimen is shown in Fig. 1.

TESTS ON STEEL PLATE

Metallic Arc D.C. Welds

The specimens were received in the as-welded condition. Two 6 x 15 inch plates were beveled along the 15 inch dimension with a 45° scarf angle and welded by the D.C. arc process. The welding current of 200 amperes and voltage of 19 volts was used with a light coated electrode. The plates were of .25 carbon steel with the following chemical composition:

Carbon .25%
Manganese .57%
Sulphur .022%
Phosphorus .016%

After the plates were welded, they measured 12 x 15 inches, the weld being at right angles to the direction of rolling of the steel plate.

The strips were cut to the required length with the weld in the center and turned down on a lathe to the tensile specimen with the dimensions shown in Fig. 1.

Three specimens were broken at each temperature at 20°, 0°, −20°, −40°, −60° and −80° centigrade.

The tensile impact value, per cent elongation, and per cent reduction in area are plotted against the temperature. Figure 2 shows that the tensile impact value is lowered somewhat with the reduction in temperature, with a sharp reversal in strength at −40°.

The results of the tests on the D.C. lightly coated arc welds indicate a wide variation in impact strength, reduction in area and per cent elongation.

In making the D.C. welds, the welder made three passes on the beveled seam first and then inverted the plate to make the final pass on the under side.

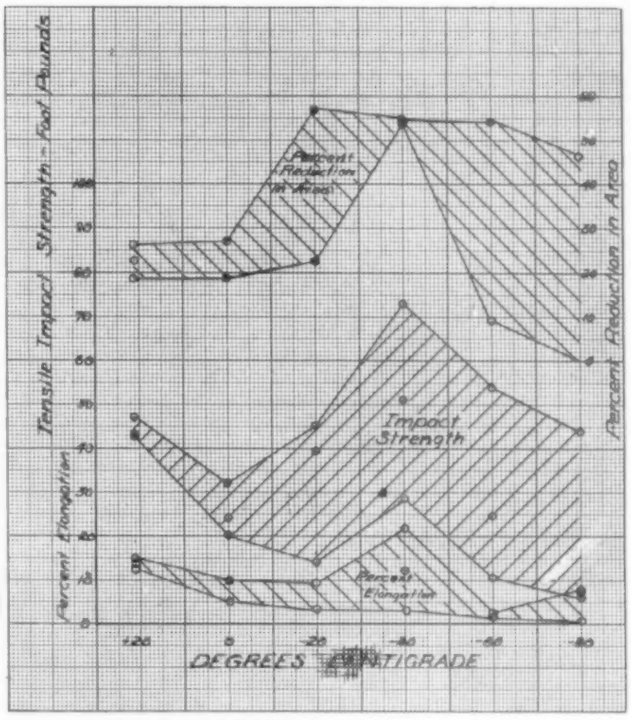


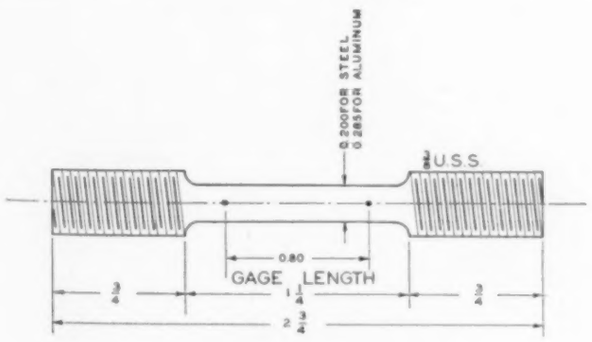
Fig. 2—Tensile Impact Properties of D.C. Arc Steel Welds at Low Temperatures

A.C. Arc Steel Welds

In contrast to the poor physical properties shown by the D.C. lightly coated arc welds, the results of the tests upon A.C. arc welds indicated uniform properties with a high average strength, decreasing slightly with the lowering temperature, Fig. 3.

As in the D.C. arc welds, the reversal of impact strength at −40° C. is again found.

The increase in brittleness due to the low temperatures is evidenced by the drop in the per cent elongation curve.



TENSILE IMPACT SPECIMEN
Fig. 1

* Abstracted from B.S. theses in the Department of Mechanical Engineering, Polytechnic Institute of Brooklyn by George L. McFarland, Jr. and George P. De Rosa. Submitted as a contribution to the Fundamental Research Division, Welding Research Committee.

† Assistant Professor of Mechanical Engineering, Brooklyn Polytechnic Institute.

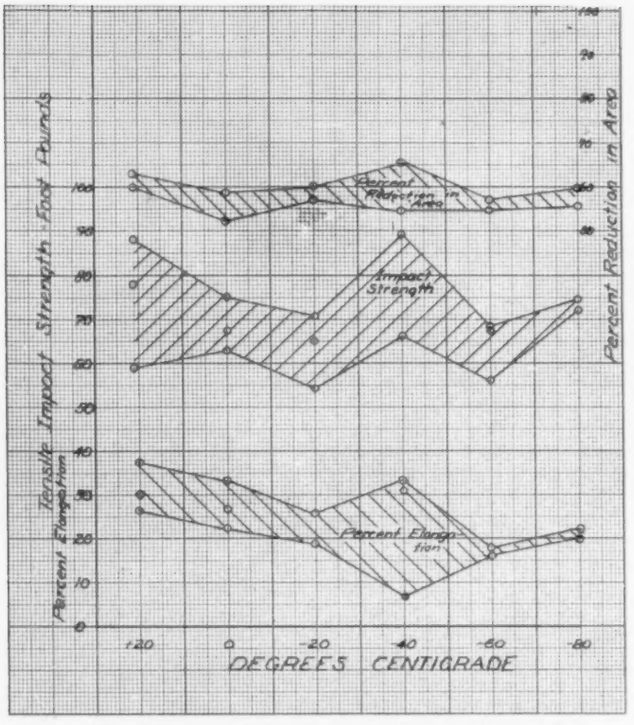


Fig. 3—Low Temperature Tensile Impact Properties of A.C. Arc Steel Welds

The local deformation, remained almost constant (shown by the reduction in area) showing that the impact energy was probably transmitted to the softest material where failure occurred.

The fractures of the A.C. arc welds all occurred outside at the junction of the weld. Again this checks closely with the theory that the harder weld-metal transmitted the energy to the softer, more ductile, parent metal.

The fine silky fractures with the cup and cone characteristics in all cases, give indication of good welding practice.

Results of Tests Upon Atomic Hydrogen Steel Welds

The results of the test are given in Fig 4.

Thirteen of the specimens out of the 18 tested showed fairly uniform results, the impact strength reversing at −40° to an average of 76 foot-pounds. At −80°, three of the four specimens tested had very low impact values neighboring around 8 to 14 foot-pounds. One specimen, however, gave an impact value of 66 foot-pounds, with good elongation and reduction in area.

The per cent reduction in area and the per cent elongation dropped only slightly, with no noticeable spread, except for the weak specimens mentioned before. The properties of these specimens are shown in the curves by the dotted lines.

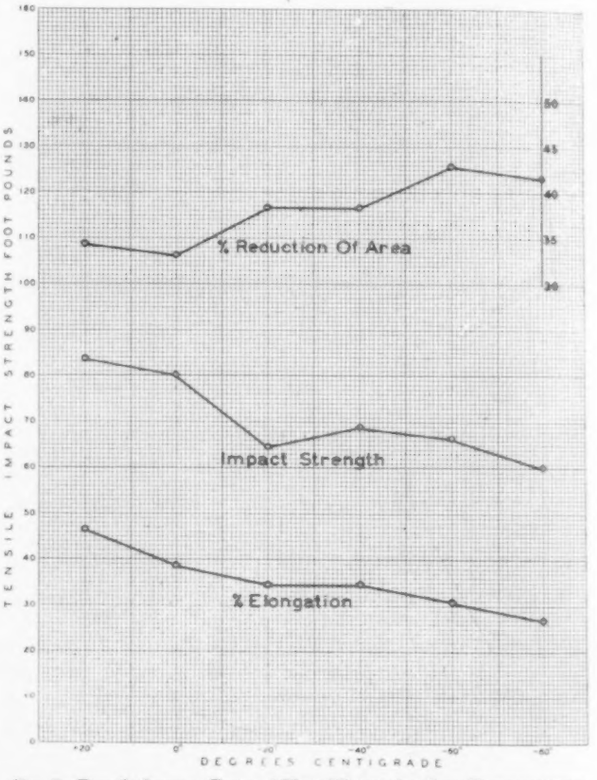


Fig. 5—Tensile Impact Tests of Plate Material at Low Temperatures (U. S. S. Specimens)

In every case, a coarse crystalline break was indicative of low impact values.

Oxyacetylene Welds

Oxyacetylene welds in Steel Plate were furnished by the Union Carbide and Carbon Corporation and the U. S. Steel Corporation.

The steel specimens supplied by the Union Carbide and Carbon Research Laboratories had a welding groove of 75 degrees and the weld made in one pass. After the plate was welded the welding seam was normalized by reheating with a flame from the oxyacetylene torch. This heating started at one end and advanced to the other at four inches per minute.

The U. S. Steel welds were supplied in the finished form and already for testing. The process of making

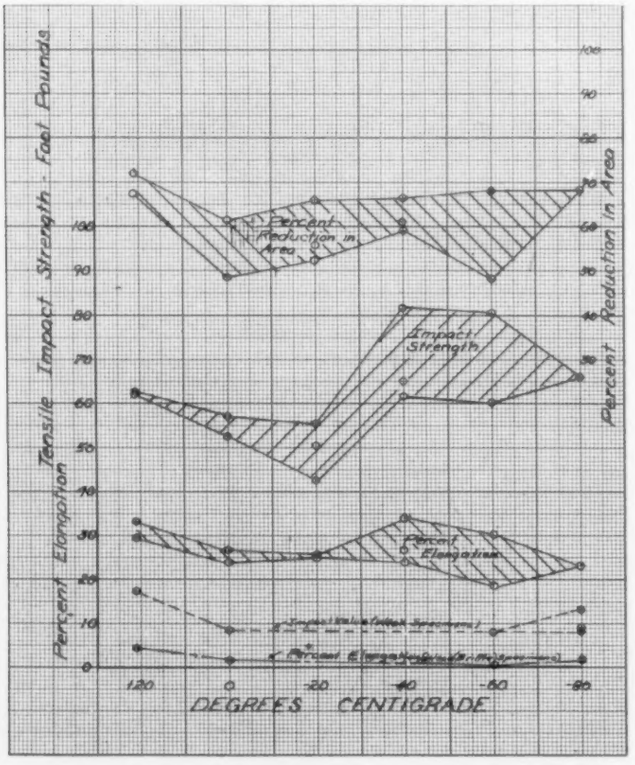


Fig. 4—Tensile Impact Properties of Atomic Hydrogen Steel Welds at Low Temperatures

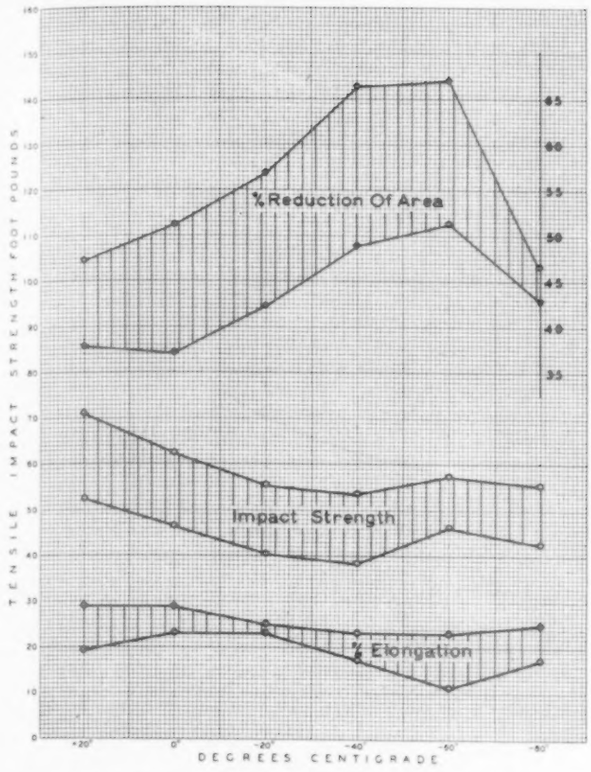


Fig. 6—Tensile Impact Tests of Oxyacetylene Welds at Low Temperature (U. S. S. Specimens)

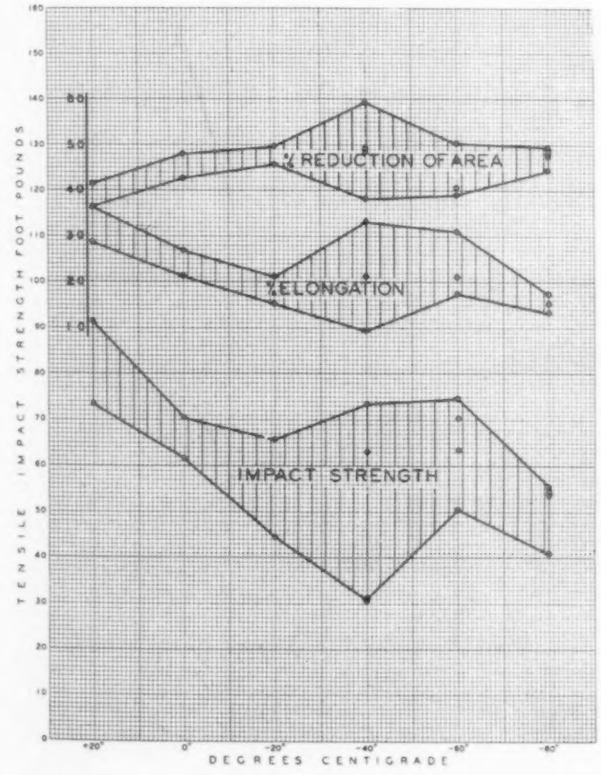


Fig. 7—Tensile Impact Tests of Oxyacetylene Welds at Low Temperatures (U. C. & C .Specimens)

these was the same as that used by Union Carbide and Carbon Research Laboratories. The result of tests on Plate Material (U.S.S.) is shown in Fig. 5 and corresponding welds in Fig. 6. The results of tests of oxyacetylene welds (U.C.C.) are shown in Fig. 7.

Resistance Butt Welds

In this process two pieces of rod $^3/_8$ inch in diameter and 2 inches long are pressed together. A large current is then passed through the joint until it has reached welding temperature. The current is stopped and further pressure is applied, upsetting the joint and completing the weld. The completed welds were then machined to the required dimensions.

Results are shown in Fig. 8.

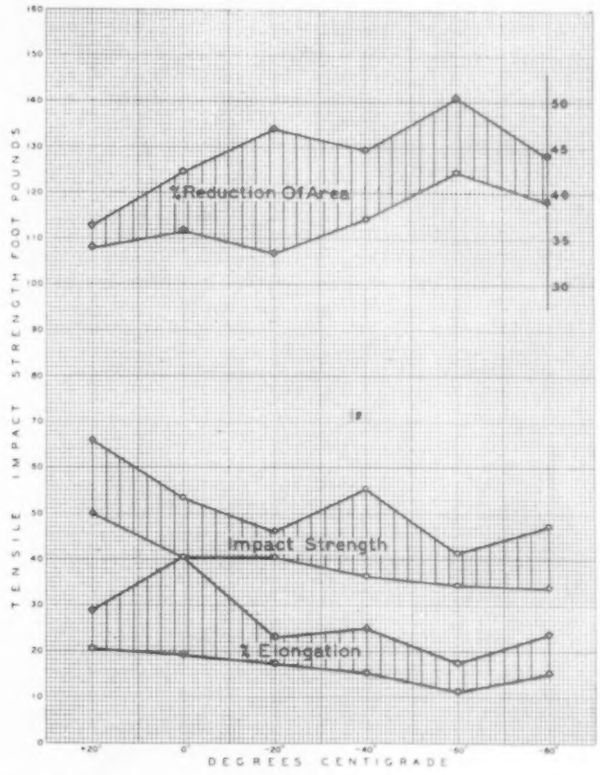


Fig. 8—Tensile Impact Tests of Resistance Welds at Low Temperatures

Discussion of Results

The falling off in tensile impact strength for good welds in mild steel from room temperature to $-80°$ C. is no more serious than the falling off in strength of the base metal. Actual values at $-80°$ C. are 75% of strength at room temperature for the base metal, 60 to 78% for gas welds, 75% for resistance welds, 88% for A.C. shielded arc welds, and 45% for D.C. welds made with lightly coated electrodes. Not enough data were available on atomic hydrogen welds.

Actual comparison in foot-pounds between processes are of no particular significance as much depends on technique, filler material and heat treatment.

TESTS OF ALUMINUM ALLOYS

All the aluminum specimens were supplied by the Aluminum Company of America.

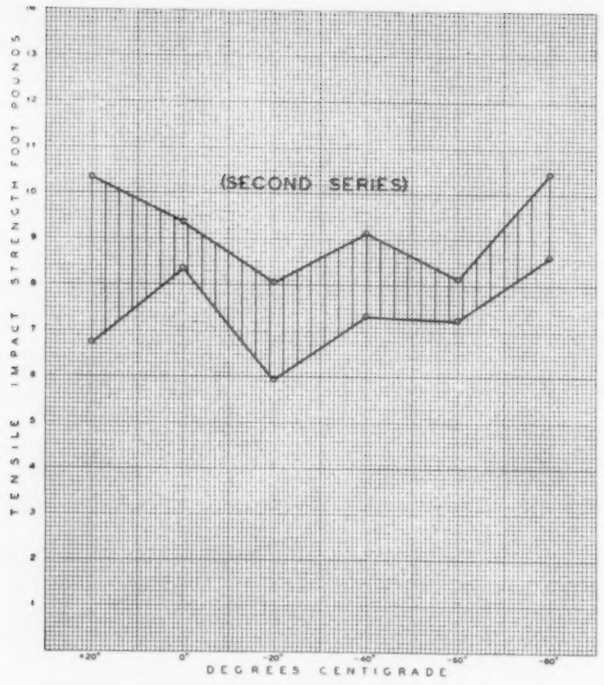


Fig. 9—Tests of Aluminum Alloy No. 43 at Low Temperatures

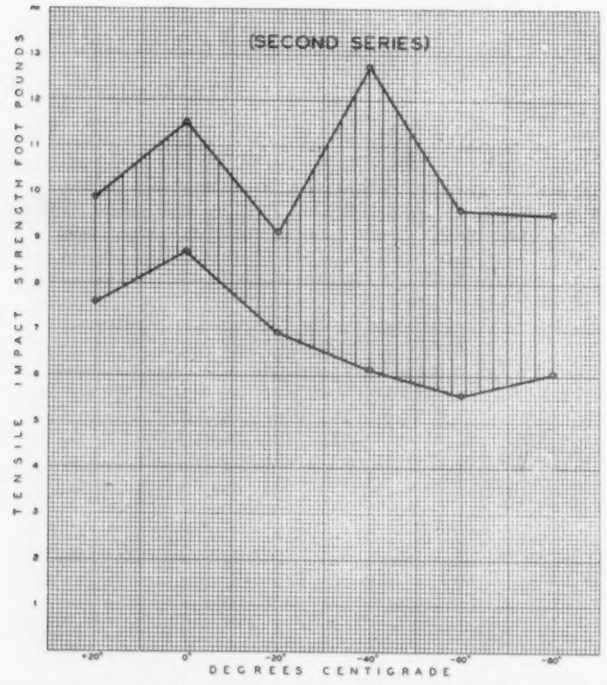


Fig. 10—Tests of Oxyacetylene Welds in Aluminum Alloy No. 43 at Low Temperatures

Both alloys are used for casting and hence the specimens were of cast stock. The alloy 195T4 is an aluminum base alloy containing 4 per cent of copper and having the iron and silicon content definitely controlled. The T4 designation of this alloy indicates that it has received the T4 heat treatment, which is a heating process for twelve hours at 960 degrees Farenheit followed by a boiling water quench. A peculiar feature of this alloy is its age hardening effect when allowed to remain at room temperature; this necessitated keeping the specimens in a Frigidaire until they were ready to be tested.

Alloy No. 43, also a casting alloy, contains five per cent of silicon. Its static tensile strength is lower than the

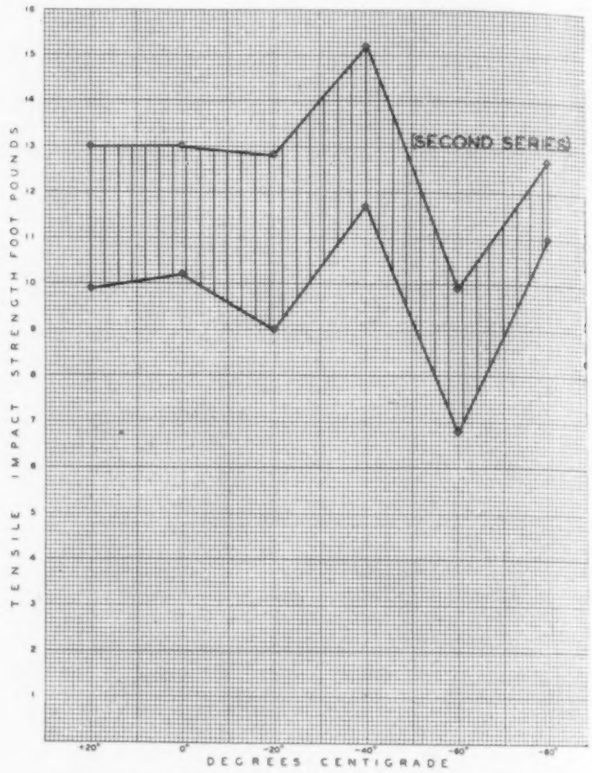


Fig. 11—Tests of Aluminum Alloy No. 195T4 at Low Temperatures

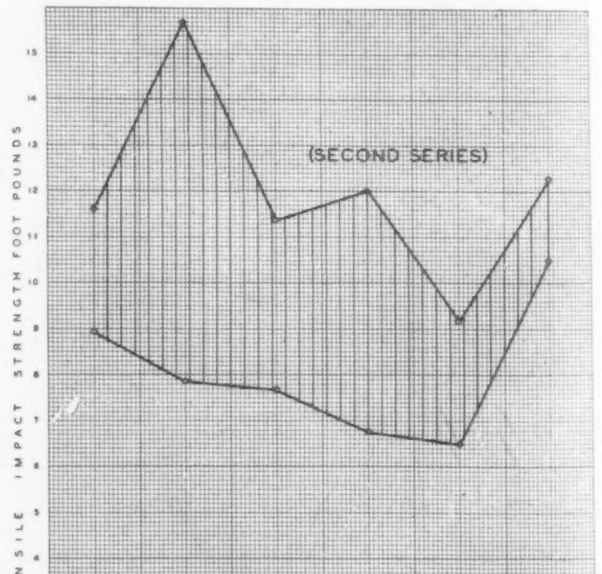


Fig. 12—Tests of Oxyacetylene Welds of in Aluminum Alloy No. 195T4 at Low Temperatures

aluminum copper alloy, but is appreciably more ductile and resistant to shock; this alloy does not receive any heat treatment.

In preparing the plates for specimens, a casting was made of each alloy in the form of a plate 12 inch x 15 inch x 3/8 inch. A 45° bevel along the 15 inch length was made. The two sections were then set so as to form a groove of 90 degrees down the middle. Into this groove was added the weld-metal which was of the same composition as the base metal; the operation was completed in one pass of the metal; after this, the plate was cut into 3/8 inch square x 12 inch long pieces having the weld in the center. These in turn were machined to the required dimensions shown in Fig 1; in the case of alloy 195T4 it received the heat treatment after machining, to relieve only stresses that may have been set up.

Results of tests on plate material No. 43 are shown in Fig. 9. Oxyacetylene welds in this material are shown in Fig. 10. Corresponding values in aluminum alloy No. 195T4 are shown in Figs. 11 and 12.

Discussion of Results

It is noticed that alloy No. 195T4 is the stronger of the two averaging about 7% higher in impact value. The two alloys lose strength with a decrease in temperature, but only down to −60 degrees Centigrade; at this point they take a turn and get stronger. All the sets showed an increase in strength at the lowest temperature.

The actual impact values of plate and welds for alloys No. 43 and 195T4 at −80° C. were practically the same as at room temperature. This indicates the value of aluminum in structures or parts subject to low temperature.

AN INVESTIGATION of the TENSILE and Torsional Strength of Weld-Metal and Welded Joints*

By JOHN R. GRANDINETTI

IN THIS investigation D.C. welds (200 amp.) were made with 3/16 inch and 1/4 inch diameter mineral coated electrodes.

None of the medium steel plates and bars which were welded to obtain the test specimens were in any way restrained during the welding process. They were freely allowed to distort due to the shrinkage of the weld-metal upon cooling. It was found that there was a greater amount of shrinkage and therefore more distortion of the welded plates when the weld-metal was deposited in a series of beads (Bead Type Weld), than when deposited in a series of layers (Layer Type Weld). It was also found that peening the successive passes of the weld-metal greatly reduced the amount of distortion of the welded plates.

The density of the weld-metal as deposited was found to be 7.85 grams/cc. and the base metal, 7.83 grams/cc. This analysis showed that a weld was produced of nearly the same density as the base metal.

PREPARATION OF TENSION TEST SPECIMENS

1. Two sets of two medium steel plates were cut to the cross section and length shown in Fig. 1. The plates were placed parallel to each other with their bases 5/16 inches apart and their inside surfaces forming a 60° angle. The plates were then welded together as indicated—one set having the weld-metal deposited in a series of beads, and the other set with the weld-metal deposited in a series of layers. Each layer of the weld-metal at the section marked "P" was peened with a small pneumatic hammer.

2. The welded plates were then cut along the transverse lines "C—C" Fig. 1 thereby obtaining four specimens from each set. One specimen from each set was peened cold; the second, from each set, was left as welded; the third from each set, was stress-relief annealed at 1200° F. for 1 1/2 hours; and the fourth, from each set, was annealed at 1620° F. for 1 1/2 hours to refine the grain structure of the weld-metal which had a carbon content of about 0.05% (after deposited), then cooled to 1000° F., and then annealed again at 1550° F. for 1 1/2 hours to refine the grain structure of the medium steel plates, which had a carbon content of about 0.25%.

3. The eight specimens from both sets were then machined to the test-specimen size shown in Fig. 2.

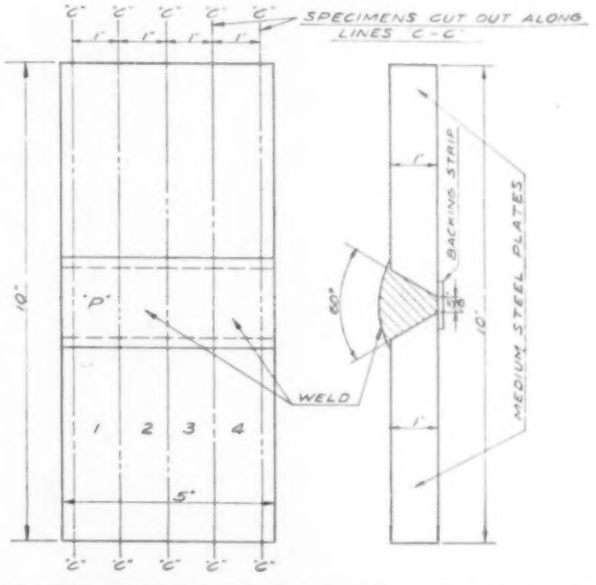


Fig. 1—Preparation of Tension Test Specimens with V-Type Welded Joint at Center

* A thesis submitted to the Faculty of the Towne Scientific School of the University of Pennsylvania for the degree of Master of Science in Mechanical Engineering. Presented, June 1938. A contribution to the Fundamental Research Division, Welding Research Committee.

Table 1—Tension Tests
Specimens with V-Type Welded Joint

	Bead Type Weld				Layer Type Weld			
	Specimen As-Welded	Specimen Peened Cold	Specimen Annealed at 1200° F.	Specimen Annealed at 1620° F. & 1550° F.	Specimen As-Welded	Specimen Peened Cold	Specimen Annealed at 1200° F.	Specimen Annealed at 1620° F. & 1550° F.
Elastic limit load (from curves) lb.	6905	6915	6560	5125	6930	7000	6300	5260
Area of test section	0.1987	0.1987	0.1925	0.2015	0.1995	0.1999	0.201	0.2011
Reduced area after testing (sq. ins.)	0.0908	0.0908	0.0708	0.0708	0.0908	0.1075	0.0661	0.0708
% Elongation in 2 inches	19.5	20.0	24.0	25.0	16.0	19.0	25.5	25.0
% Area reduction	54.3	54.3	62.3	64.8	54.5	46.2	67.1	64.8
Elastic limit (lb./sq. in.)	34,700	34,800	34,100	25,400	34,800	35,000	31,300	26,100
Ultimate strength (lb./sq. in.)	65,800	65,400	60,200	56,300	58,500	59,200	59,000	54,700
Modulus of elasticity	28,900,000	29,000,000	28,400,000	25,400,000	29,000,000	29,200,000	31,300,000	26,100,000

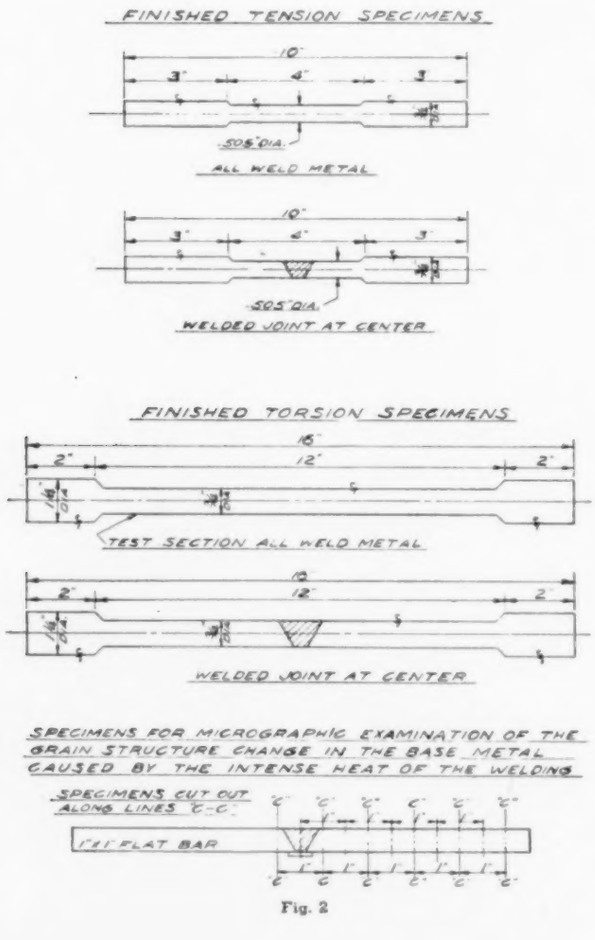


Fig. 2

PREPARATION OF TORSION TEST SPECIMENS

1. Two sets of two medium steel plates were cut to the cross section and length shown in Fig. 3. The plates were welded together as previously described—one set with the bead type weld, and the other with the layer type weld. Each layer of the weld-metal at section marked "P" was peened with a small pneumatic hammer.

2. Four specimens were then cut out of each set of welded plates along the transverse lines "C—C" Fig. 3. The eight specimens from both sets were then built up at their ends with weld-metal so that a diameter of $1^1/_4$ inches could be finally machined at the ends to suit a Riehle Torsion Testing Machine.

3. One specimen from each set was peened cold; the second, from each set, was left as welded; the third, from each set, was stress-relief annealed at 1200° F. for $1^1/_2$ hours; and the fourth, from each set, was annealed at 1620° F. for $1^1/_2$ hours to refine the grain structure of the weld-metal (0.05% C), then cooled to 1000° F., and then annealed again at 1550° F. for $1^1/_2$ hours to refine the grain structure of the medium steel plates (0.25% C).

4. The eight specimens from both sets were then machined to the test-specimen size shown in Fig. 2.

CONCLUSIONS

Tension Tests

The results of the Tension Tests, Table 1, show that the welded joints developed elastic and ultimate strengths which are equivalent to those of a good grade medium steel

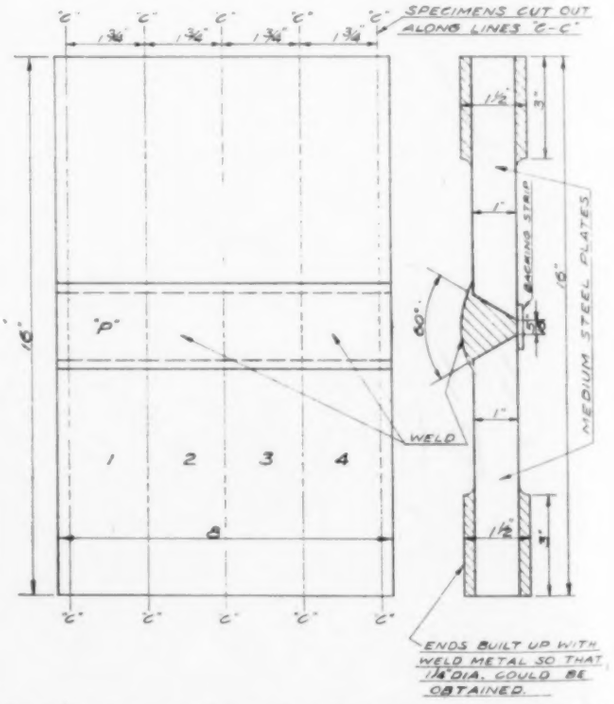


Fig. 3—Preparation of Torsion Test Specimens with V-Type Welded Joint at Center

and can therefore be classed as 100% efficient. The only specimens that tested less than 100% efficient were those that were annealed at 1620° F. and 1550° F., which treatment would normally be expected to reduce the strength properties. This leads to the conclusion that from the standpoint of strength characteristics and practicability of annealing fabricated welded structures, that 1200° F. is the maximum temperature to be recommended for heat treatment.

Results also indicate that the Layer Type of weld deposit produces a higher elastic limit than the Bead Type, and is consequently the better weld from the structural standpoint. It is also indicated that cold peening slightly improved the elastic limit, ultimate strength and the ductility in both the Bead and Layer Types of weld deposit.

Results indicate that the specimens that were cold peened were slightly higher in elastic limit (for shear) and ultimate twisting strength than the "as-welded" specimens in both the Bead and Layer Types of weld deposit. It is also evident from the total and unit angles of twist that cold peening increased the ductility of the weld-metal over the "as-welded" condition.

The results also show that the properties of the Bead and Layer Types of weld deposit are the same for torsional loading as for tensile loading, and that the Layer Type of deposit produces a higher elastic limit than the Bead Type.

Torsion Tests

From the Torsion Tests, Table 2, it can be concluded that for torsional loading of welded structures, joint efficiencies can be considered about 90% on the basis of the ultimate shearing strength of the base metal, and about 70% on the basis of the elastic limit (for shear) of the base metal; whereas for tensile loading, the results indicated the joint efficiency to be 100% on the basis of both the elastic and ultimate strengths of the base metal.

Table 2—Torsion Tests

	Total Angle of Twist in Degrees	Ultimate Twisting Strength $S_u = Pp/(J/c)$ Lb. per Sq. In.
Bead Type Weld		
As-welded	714	41100
Peened cold	808	42000
Annealed at 1200° F.	1219	42100
Annealed at 1620° F. & 1550° F.	1150	40800
Layer Type Weld		
As-welded	590	39300
Peened cold	644	40200
Annealed at 1200° F.	1737	41300
Annealed at 1620° F. & 1550° F.	1020	41400

LIGHT FLOORS FOR HIGHWAY BRIDGES*

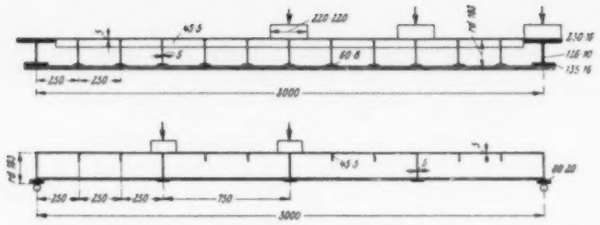
By PROFESSOR OTTO GRAF†

STATIC load-deflection and load-strain measurements were made on four types of arc-welded light bridge floors, Fig. 1, with different distributions of load on the floor. The cellular type is particularly efficient, and simple approximate design formulas are valid. It is essential that the transverse tension members be continuous in order than the floor undergo adequate deformation before failure. In the cellular floor shown in Fig. 1 (*a*) these tension members were not welded to the flanges of the longitudinal beams. The deflections and the strains (tension fiber) for load applied on an area of 8.6 x 8.6 inches at the center of the floor are recorded in Table 1 for each of the thirteen longitudinal beams. The strain curves for the floor beams are not the same as for a single beam because the transverse tension members create irregularities. With central loading, as the load is increased the ratio of strain of the middle beams to the strain of the edge beams decreases. In other words, the border beams support increasingly larger proportions of the load as it is increased. If it is assumed that all the beams carried the same load as that calculated for the middle beam, calculation shows that the floor consists of 7 instead of 13 longitudinal beams. If the load is imposed on the border of the floor the neighboring beams assume smaller proportions of load than if the load is central. Under maximum load, which was 57 to 63% higher than that calculated from the yield strength and moment of the beams, all beams were fully used. The Ostenfeld method of designing cellular floors is in agreement with model tests using small bars and with the static tests of the floors themselves. Static load tests of a welded bridge floor in service were in agreement with design calculations. Dynamic tests with the aid of an oscillograph revealed that the cellular floor was not particularly susceptible to vibrations under the action of an 18-ton Diesel truck moving at speeds up to 30 miles per hr.

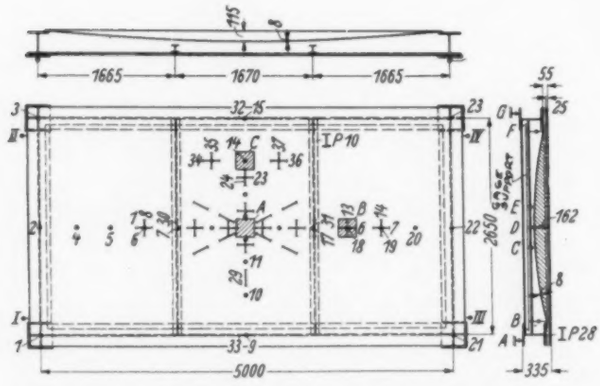
The welded buckle plate floors behaved satisfactorily, but the basis for the design of buckle plates requires development. The permanent deflection in the middle with a central load of 20 tons is 0.20 inch. The effect of this permanent deformation is that only elastic deflection occurs when a central load of 13 tons is applied subsequently. The maximum stress in the plate under a central load of 13 tons is 14,500 lb./in.^{2} Of practical interest is the fact that the transverse stiffeners have practically no effect on the strain in the buckle plate. With increasing load the first strain lines appear (66 tons) in the plate at the middle of the long edge. At this load flow lines are found on the upper flange of the long border beams. The strain in the plate increases slowly as the time of application of load is increased. Recovery on removal of load also depends on the time. If the floor is covered with bituminous material the distribution of load depends to a great extent on the time of application. The deflections of the coated floor may

* Abstracted by Dr. G. E. Claussen, Research Assistant, Welding Research Committee, from *Aus Untersuchungen mit Leichtfahrbahndecken zu Strassenbrucken*. Report of the German Structural Steel Committee, Series B, Heft 9, 1938, 25 pp., published by J. Springer, Berlin.

† Technical College, Stuttgart, Germany.

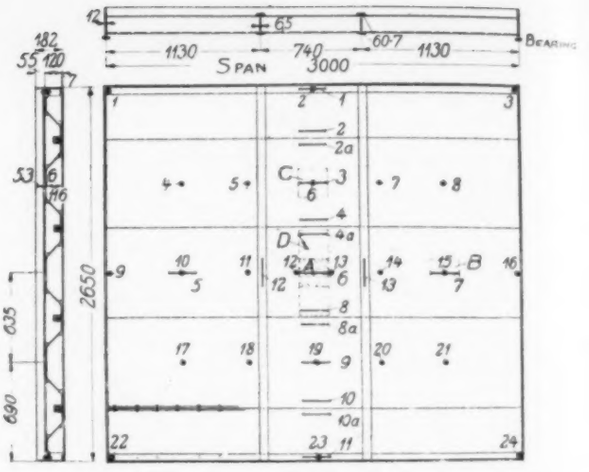


(*a*) Cellular floor (B4). Total height of floor above roller supports was about 7¼ inches
Upper diagram = cross section
Lower diagram = longitudinal section
Arrows indicate different locations of test loads

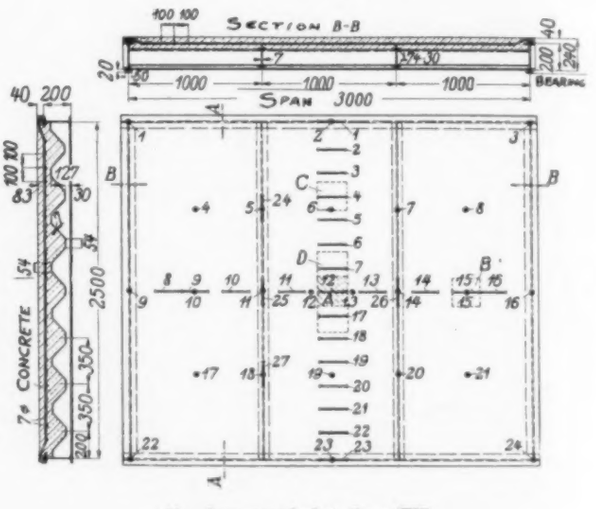


(*b*) Buckle plate floor (II). Supported on steel balls at the corners
● gage points for deflections
⟼ gage lengths for strains
IP 28 = H section; breadth of flange = height of beam = 11.0 inches; flange thickness = 0.79 inch; web thickness = 0.47 inch; 76 lb./ft.

Fig. 1—Types of Floors Tested. Several Modifications of Each Type Were Used. Dimensions in Millimeters



(*c*) Double angle floor (K1)



(*d*) Corrugated plate floor (EII)

Table 1—Deflections and Strains† of Welded Cellular Steel Floor (Fig. 1 (*a*))

Load, Tons		1	2	3	4	5	6	7*	8	9	10	11	12	13
6.6	Strain, inch/inch	0.00008	0.00008	0.00013	0.00015	0.00015	0.00021	0.00026	0.00022	0.00017	0.00010	...	0.00010	...
6.6	Deflection, inch	0.022	0.027	0.035	0.037	0.052	0.060	0.060	0.054	0.047	0.045	0.028	0.022	0.010
13.2	Strain, inch/inch	0.00011	0.00016	0.00020	0.00022	0.00032	0.00043	0.00056	0.00043	0.00035	0.00025	0.00022	0.00016	...
13.2	Deflection, inch	0.036	0.054	0.066	0.078	0.096	0.115	0.122	0.109	0.093	0.086	0.065	0 053	0.028

* The load was placed over beam 7.
† Dial extensometer, gage length = 8 inches.

be up to 60% smaller in cold weather than in hot weather.

The tests on the double-angle and corrugated plate floors, Fig. 1 (*c*) and (*d*), show that the transverse stiffening must be increased to support concentrated loads. With a concentrated load at the center the deflections of the welded double-angle floor, Table 2, reveal a less favorable distribution of deflections than for a cellular floor, according to expectations. The central double angle failed by buckling at a maximum load of 20 tons, corresponding to a calculated stress of 24,000 lb./in.² in the lower surface of the double angle. Evidently the floor is not suited to withstand concentrated loads. Covering the floor with concrete improves the distribution of load.

The corrugated plate floor is covered with concrete, as shown by the shading in Fig. 1 (*d*). At a load of 22

Table 2—**Deflections (Inches) of Welded Double Angle Floor**

Location (see Fig. 1 (*c*))	Under a Load of 11 Tons	Under a Load of $16^1/_2$ Tons	Permanent Deflection, Inch, After Removal of $16^1/_2$ Tons
at 2 at the right border	0.075	0.095	0
at 6	0.22	0.34	0.024
at 12 and 13 (middle)	0.31	0.50	0.056
at 19	0.21	0.34	0.028
at 23 at the left border	0.071	0.095	0

tons the elongation of the tensile (lower) fibers of the corrugations is:

Gage length no.	2	4	6	12	18	20	22
Elongation, inch/inch	0.26	0.36	0.43	0.80	0.44	0.32	0.27

Adding 1.6 inches of concrete to the top of the floor improves the distributions of load, and reduces the stresses by 50%. With gradually increasing load cracks were heard at a load of $62^1/_2$ tons for the floor shown in Fig. 1 (*d*), and at a load of $60^1/_2$ tons for the floor with 1.6 inches additional height of concrete. The maximum load for the former floor is 77 tons; for the latter, 88 tons. At these maximum loads the tensile stress in the plate and beams at the border of the floor remained below the yield strength. Failure occurred by tearing of the welds joining the corrugated plates to the transverse stiffeners.

Fatigue Tests of Welded Rail Joints*

By **PROFESSOR F. CAMPUS**†

THE Belgian National Railways has adopted flash welding for rail joints. Main line joints are annealed 50 minutes at 875° C. before being placed in service. Static and pulsating bend fatigue tests were made on the unwelded rail and on welded joints with or without heat treatment. The rails (101 lb./yard) were secured from several mills. All tests were made in simple bending with concentrated load at mid span (span = 36 inches).

Static bend tests with Huggenberger extensometers and with head in tension showed that, on account of the short span, the neutral axis of an unwelded rail was 1.81 inches from the foot (total height of rail = 5.94 inches) instead of the theoretical 2.80 inches. The proportional limits (lb./in.²) were:

	Head in Tension	Head in Compression
Unwelded rail	48,000	70,000
Unheat-treated joint	42,000	47,000
Heat-treated joint	49,000	49,000

The pulsating bend fatigue tests were performed on a 110-ton Amsler pulsator equipped with cylindrical mild steel supports on a rigid foundation. The stress in the tension fiber varied from an upper tensile stress to a lower tensile stress of 5800 lb./in.² When the upper stress was below 55,000 lb./in.² the frequency was 500 cycles/minute; above 55,000 lb./in.² the frequency was 250 cycles/minute to avoid overheating the oil. It was believed that the load varied with the frequency, but no correction was made for possible errors. The load probably exceeded that indicated by the manometers.

* Abstract of Essais de fatigue de joints soudés de rails, published in Revue Universelle des Mines, 8th Series, vol. 14, No. 6, 493–499, June 1938.

† University of Liège, Belgium.

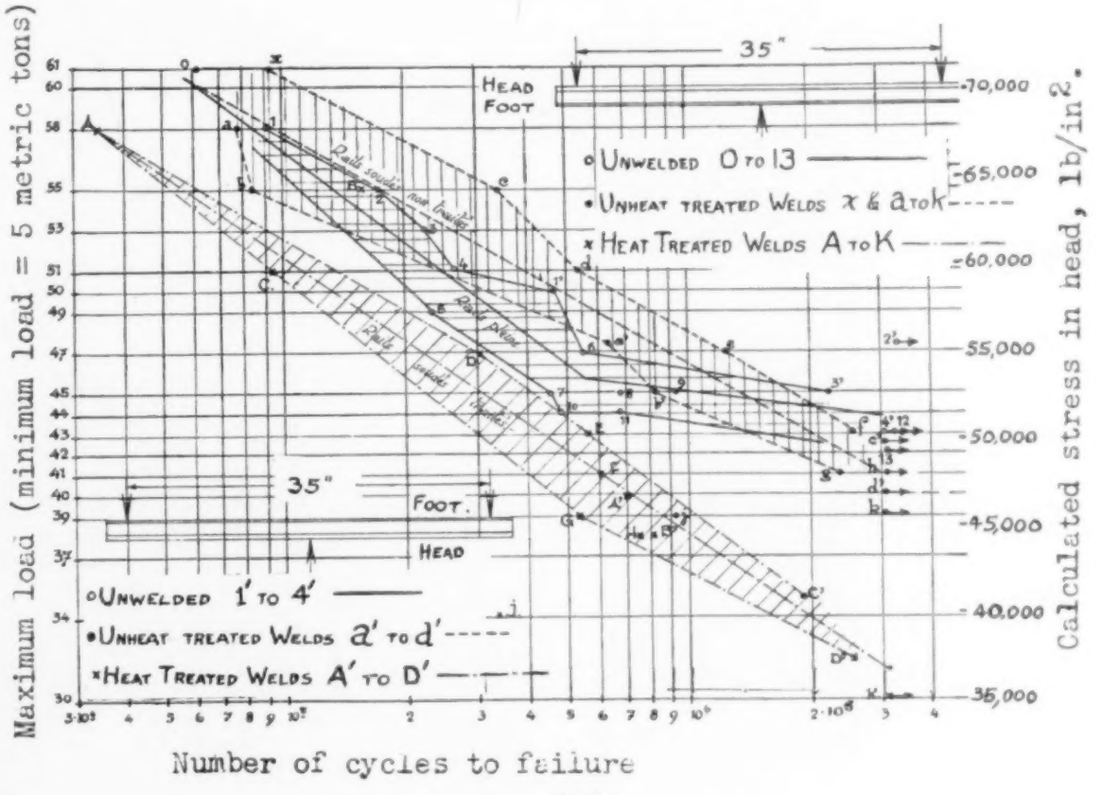


Fig. 1

The results of 47 tests are shown in Fig. 1. Whether the head is in tension or compression appears to have no effect on the pulsating bending fatigue strength, but has considerable effect on the type of failure. With the head in compression cracks started in the head close to the support. These cracks had little effect on the strength of the rail, for a rail in which the first crack appeared after 4,300,000 cycles withstood 8,856,000 cycles (5800 to 60,500 lb./in.^{2}) without failure. The cracks spread gradually during test and were similar to those formed under heavy wheel loads in service.

Fatigue failure in the welded rail sometimes occurred in the weld, sometimes $^3/_4$ to 4 inches outside the weld. Welds (*J*) made from rails of different make were inferior to joints between rails from the same mill.

Extrapolating the semi-logarithmic diagram to 10 million cycles (estimated to be equivalent to 8 years main line service) it was calculated that the endurance limit of unheat-treated joints would be 85% of the endurance limit of unwelded rails. The endurance limit of heat-treated joints was estimated to be 57% of unwelded rails.

New Girder Construction

A new kind of plate girder construction, Fig. 1, was exhibited by the Arcos firm at the 1938 Leipzig Fair. In place of the customary flange plate a relatively thin bent plate is substituted. In this way the weld is removed from the vicinity of the most highly stressed fiber

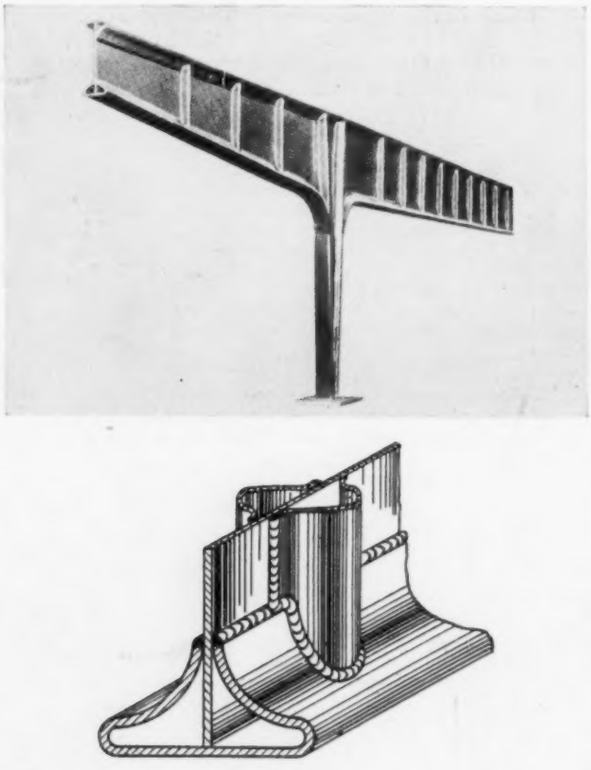


Fig. 1

and greater stiffness is achieved. Distortion is less troublesome, too. For the sake of appearance mainly the stiffeners are also hollow sections. In this type of construction there is practically no place for rain water to lodge. (*Elektroschwg.*, **9**, H.6, 111–112 (1938).)

International Welding Conference

Abstract of report by G. Schaper, *Bautechnik*, **16** (26) 346–347, June 17, 1938)

ON May 19th–21st a discussion was held under the auspices of the Swiss Federal Materials Testing Institute, Dr. M. Ros presiding, at Zurich, Switzerland on the subject "Present Day Status of Welding and the Welding Specifications in Germany and Switzerland." The meeting was occasioned by the cracks that appeared in the welded low-alloy structural steel highway bridge at Rudersdorf, Germany and in the railway bridge at the Zoological Gardens in Berlin.

The defects in the two bridges that have been mentioned were quite unexpected. The cracks in the Zoological Garden Bridge originated in the weld connecting the web of a plate girder to its ribbed flange. The cracks spread into flange and web. The ends of the crack simply were drilled out. In this condition the superstructure of the bridge has been in service over two years under normal traffic and the cracks have not changed.

The cracks in the superstructure of the Rudersdorf Bridge also originated in a web-ribbed flange weld and spread over the entire flange and a large part of the web. The fine cracks in the Zoological Garden Bridge were found by a bridge inspector with a magnifying glass. It is not known when the cracks first occurred. On the other hand, it is known that two cracks in the Rudersdorf Bridge formed on the night of January 2–3, 1938 when the temperature fell from +10 to −10° C. The cracks made a loud noise and opened several millimeters. In both bridges there was no trace of deformation in the neighborhood of the cracks. The failure was of the brittle type.

This summer a number of investigations into the causes of the cracks are being prosecuted. In all probability the causes are: (1) the web-flange welds were made too rapidly with consequent hardening of the low-alloy steel in the heat-affected zone; (2) the condition of triaxial stress in the welded favored brittle fracture; (3) possibly there were rolling defects in the thick ribbed flange of low-alloy steel.

Independently of the investigations this summer, static tests of welded low-alloy steel I beams 20 inches high have been made recently in which the flanges, 1.18 inches thick were either flat, ribbed or nose-profile. Welding was either automatic or manual and the web stiffeners were welded either before or after the flange-web welds had been completed. With one exception all beams withstood a calculated extreme fiber stress of 77,000 to 85,000 lb./in.^{2} without fracture. The deformation was severe and failure was due to buckling of the compression flange. In the single exception, a crack originated at the flange-web weld and spread as a brittle fracture through the entire height of the beam at a calculated extreme fiber stress of 77,000 lb./in.^{2} These tests offer no explanation for the Berlin and Rudersdorf failures, which occurred at calculated extreme fiber stresses of not over 21,300 lb./in.^{2} Probably the small test beams did not reproduce conditions in the bridges.

Summarizing the results of these tests, there is no reason to discard welding for bridges. Mild steel bridges can be welded with complete security and it is expected that as a result of the present tests low-alloy steel bridges may be welded without misgivings. However, bridge welding is an art and only experienced firms should be entrusted with it.